STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

GEOLOGY OF THE BRECKENRIDGE MOUNTAIN QUADRANGLE CALIFORNIA

BULLETIN 168
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DIVISION OF MINES
FERRY BUILDING, SAN FRANCISCO

STATE OF CALIFORNIA
EARL WARREN, Governor
DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, Director

DIVISION OF MINES
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OLAF P. JENKINS, Chief

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GEOLOGY OF THE BRECKENRIDGE MOUNTAIN QUADRANGLE CALIFORNIA

By T. W. DIBBLEE, JR. and CHARLES W. CHESTERMAN

LETTER OF TRANSMITTAL

To His Excellency
THE HONORABLE EARL WARREN
Governor of the State of California

SIR: I have the honor to transmit herewith Bulletin 168, *Geology of the Breckenridge Mountain Quadrangle, California,* prepared under the direction of Olaf P. Jenkins, Chief of the Division of Mines, Department of Natural Resources. The report is accompanied by a detailed colored geologic map together with cross sections, charts, and photographs of the area which lies in the southern Sierra Nevada about twenty miles east of Bakersfield in Kern County. This map and its report represent one of the results of the Division's program of basic geologic mapping. The senior author, T. W. Dibblee, Jr., has mapped not only this Breckenridge Mountain quadrangle, but has mapped many other areas in the state, including western Santa Barbara County and the Saltdale quadrange, published by the Division as Bulletins 150 and 160 respectively. The junior author, Charles W. Chesterman, a staff member of the Division, sampled the complex rocks of the area and made a petrographic study of them to supplement the field investigation.

The Breckenridge Mountain quadrangle contains gold mines and also tungsten deposits north of Walker Basin. In the southwestern part of the quadrangle, wells were drilled for oil and two of them have produced small amounts of heavy petroleum. The earthquakes of 1952, which caused severe damage in the area of Arvin and Tehachapi, were caused by earth movements along the White Wolf fault. This and other major faults are actually shown on Breckenridge Mountain quadrangle.

Bulletin 168 should provide basic information for mining, for the development of oil fields, in the study of other natural resources, and in structural engineering problems.

Respectfully submitted,

WARREN T. HANNUM, Director
Department of Natural Resources

August 27, 1953

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GEOLOGY OF THE BRECKENRIDGE MOUNTAIN QUADRANGLE, CALIFORNIA†

By T. W. Dibblee, Jr.,* and Charles W. Chesterman **

ABSTRACT

The fifteen-minute Breckenridge Mountain quadrangle, the center of which lies 20 miles east of Bakersfield, takes in a portion of the southern Sierra Nevada and extends down to the margin of San Joaquin Valley. The northern half of the quadrangle is a plateau-like area rising gradually from the western foothills to the north-trending ridge of Breckenridge Mountain. This rising plateau is abruptly terminated on the east by a steep escarpment facing the 3,500-foot high valley of Walker Basin. The southern portion of the quadrangle is likewise a westward-sloping plateau-like area rising gradually from the San Joaquin Valley at 650 feet in the southwest corner of the quadrangle, eastward to over 5,000 feet elevation; but this rising upland is breached by deeply incised canyons and tributaries of Walker Basin and Caliente Creeks flowing westward into San Joaquin Valley.

Metamorphic rocks of the area are assigned to the Kernville series composed of schists, quartzites, and crystalline limestones, of supposedly Carboniferous age, and the Pampa schist of Paleozoic or early Mesozoic age. These metasediments occur as linear inclusions within plutonic rocks which have invaded them in the northeastern, southeastern and western portions of the quadrangle.

Plutonic rocks ranging from quartz diorite to gabbro crop out over the greater part of the quadrangle, and belong to the Sierra Nevada batholithic invasion of supposed late Jurassic age. The dominant rock type is hornblende-biotite quartz diorite which usually has some planar foliation, and contains many partly digested remnants of the metasediments. The quartz diorite grades into, or perhaps is intruded by, a massive biotite quartz diorite. Gabbro, hornblendite and other ultrabasic rocks occur as small local intrusions or segregates. The plutonic and metamorphic rocks are cut by numerous pegmatite dikes in certain areas.

In the western foothills in the vicinity of lower Caliente Canyon, the plutonic-metamorphic complex is unconformably overlain by about 3,000 feet of Tertiary sediments. These are: (1) Walker formation, Oligocene(?); (2) Ilmon basalt, lower Miocene; (3) Freeman-Jewett shale, lower Miocene; (4) Bena gravels, Miocene; (5) Bealville fanglomerate, Oligocene-Miocene (facies of Walker and Bena formations); and (6) Kern River gravels, Pliocene. These are all fluviatile formations with the exception of the marine Freeman-Jewett shale.

The attitude of the Kernville series exposed in the eastern portion of the quadrangle is generally vertical with a north-south trend. The Pampa schist exposed in the western portion has the same general attitude but with a strong S-shaped flexure. The attitude of the foliation and inclusions within the quartz diorite is generally accordant with that of the enclosing metasediments. The overlying Tertiary sediments of the western foothill area dip about 20° SW. The Breckenridge Mountain plateau is a structural block tilted gently westward and elevated along the Breckenridge fault at the eastern base of this steep mountain front. This fault, a part of the Kern Canyon fault zone, dies out south of Walker Basin. Several minor normal faults trending roughly eastward are found at the western border of the quadrangle in the foothill area. The Edison fault, the largest of these, is traceable for about 9 miles from Caliente westward and dips about 35° N., bringing Tertiary sediments on the north in contact with granitic rocks on the south. Throw amounts to several thousand feet.

Mineral resources consist of small quantities of tungsten ore (scheelite) mined from garnetized limestones of the Kernville series exposed northeast of Walker Basin. Some gold has been found, but not in paying quantities.

INTRODUCTION

The topographic map of Breckenridge Mountain quadrangle, issued by the War Department, U.S. Army Corps of Engineers in 1944, covers 15 minutes of latitude and longitude on a scale of 1:62500 (1 inch equals

† Manuscript submitted for publication December, 1952.
* Geologist, Richfield Oil Corporation.
** Associate Mining Geologist, California Division of Mines.

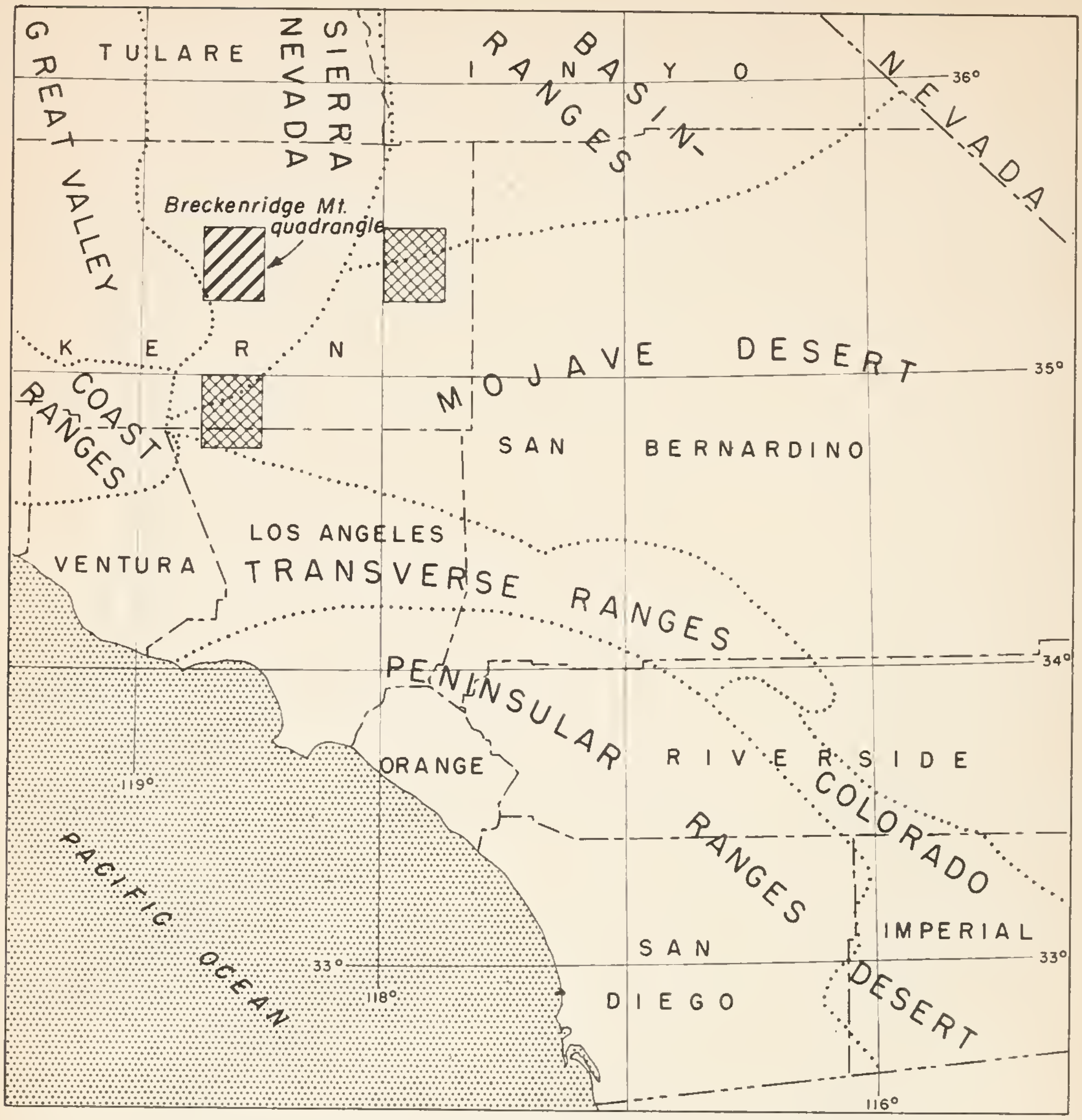

FIGURE 1. Index map of southern California showing geomorphic provinces and location of the Breckenridge Mountain quadrangle. Shown cross-hachured are other recently published geologic quadrangles of the area.

1 mile), or about 242 square miles. The center of the quadrangle is 20 miles due east of Bakersfield, California. Breckenridge Mountain quadrangle map includes the northeastern quarter of the old Caliente 30-minute map scale 1:125000 (1 inch equals 2 miles), issued in 1905 by the U.S. Geological Survey.

The southern portion of Breckenridge quadrangle is traversed by the Southern Pacific-Santa Fe Railroad, and by U.S. Highway 466, passing through Bakersfield and Tehachapi. State Highway 178 follows Kern River Canyon between Bakersfield and Kernville; the area may also be entered by several county roads. The only settlements within the quadrangle are the railroad town of Caliente and railroad camps of Bealville and Bena. Bakersfield, population 110,000, is 15 miles west of Bena.

Industry is confined largely to the raising of beef cattle made possible by excellent pasture. Part of the area southwest of Caliente is farmed, as is Walker Basin, where barley and alfalfa are grown. In the hills northeast of Walker Basin, small amounts of gold and tungsten have been produced for many years, and a small amount of heavy oil was pumped from shallow wells in the extreme southwest corner of the quadrangle.

Climate and Vegetation. In the Breckenridge Mountain area summers are warm and dry, and winters are cold with occasional rain or snow, but local climate and precipitation vary with altitude. In the low foothill area summers are hot, with daytime temperatures exceeding 100 degrees, and winters are mild except for occasional cold valley fog sometimes lasting for weeks. In higher altitudes summers are warm to mild, and winters are cold. Annual precipitation, which falls mostly during the winter months, varies from less than 10 inches in the foothill area to several times that amount in the higher mountains, chiefly in the form of rain below 3,000 feet and as snow above that level. Winter storms are generally accompanied by severe gales in passing over the mountains. Electrical storms occasionally develop over the mountains during the summer.

Vegetation within the mapped area varies considerably and is divided roughly into four zones determined by altitude, all of which grade into one another. Other factors, such as direction and steepness of slope and character of the underlying rocks, have some local influence, but are subordinate to altitude. The four zones of vegetation recognized are as follows: (1) lower zone, below 2,000 feet, made up of short grasses and annuals, and scanty low brush, chiefly burrow bush; (2) lower middle zone, 2,000 feet to 3,500 feet, grasses, annuals, scattered brush, and oak timber—chiefly post oak; (3) upper middle zone, 4,000 feet to 6,000 feet, same as lower middle zone, but with digger pine and considerable admixture of brush, chiefly scrub oak, buckthorn and mountain mahogany in dense, impregnable thickets; and, (4) upper zone, over 6,000 feet, tall timber made up of black oak, western yellow pine, white pine, and white fir. Streams throughout the area are lined with arrow-weed, willow, cottonwood, sycamore, and live oak.

Junipers and piñons are confined to the mountains east of Walker Basin and Havilah Canyon.

Rock formations are moderately well exposed over most of the quadrangle. Granitic and metamorphic rocks form prominent outcrops in steep, narrow canyons and generally on south-facing slopes. Summits and north-facing slopes are generally covered with a thick mantle of residual soil so that rock outcrops are less prominent.

Procedure. Field mapping was done directly on the Breckenridge quadrangle base, except in the southwestern portion; there it was done on aerial photographs, scale 1 inch equals 1,666 feet (approx.), and the geology later transferred to the quadrangle. Field work was carried on at various times since 1945, by the writer, assisted in the southwest portion by A. H. Warne. The major part of the field work was done during May-June 1950. Field work was completed in 33 days.

Acknowledgments. The writer is indebted to Richfield Oil Corporation for the use of aerial photographs used in mapping the geology of the southwestern portion of the quadrangle, and for the permission to publish the geology of this portion. Acknowledgment is also due A. H. Warne, who assisted in mapping the southwest portion.

Previous Geologic Work. Little has been published on the geology of the area covered by Breckenridge Mountain quadrangle, although several papers have appeared dealing with the geology of adjoining areas and with broad physiographic and structural features of the southern Sierra Nevada.

A study of the geomorphic features of the Kern River Canyon by Lawson (1904), who first recognized the Kern Canyon fault, was published in 1904, and in a later paper (Lawson 1906), he described the geomorphic features of the Tehachapi area.

Broad structural features of the southern Sierra Nevada were discussed by Buwalda (1915, 1920, 1934) ; by Hake (1928) ; and by Locke, et al. (1940).

The first paper describing various rock units in part of the Kernville quadrangle was one by Miller (1931). In a later paper Miller and Webb (1940) mapped the areal geology of this entire quadrangle. Several papers dealing with the geology of the Isabella dam site have been published, including those by Louderback (1916), and Forbes (1931). In connection with this project, the geology of the Isabella quadrangle has recently been mapped by Treasher (1949, abst.).

Little has been published on the geology of the western foothill area of the southern Sierra Nevada, except for the geology of the Tejon Hills at the extreme southern end (Hoots 1930).

Many papers on the subsurface geology and stratigraphy of the nearby eastside oil fields of San Joaquin Valley have been published. Godde (1928) described the general stratigraphy of the area. The geology of the Mount Poso oil field is described by Wilhelm and Saunders (1927), of the Round Mountain oil field by Rogers (1943), of the Edison oil field by Edwards (1943), Beach (1948), and Hewitt and May (1948).

Geologic Setting. The area covered by Breckenridge Mountain quadrangle lies in the extreme southern portion of the Sierra Nevada and is made up of a pre-Cretaceous granitic-metamorphic complex typical of the region.

The plateau-like highland of Breckenridge Mountain is topographically the extension southward of the Greenhorn Mountains, a north-trending range which forms the "Western Divide" of the southern Sierra Nevada. The Greenhorn and Breckenridge Mountains constitute a fault block tilted gently westward toward San Joaquin Valley which is roughly bounded on the east by the Kern Canyon fault zone, along which the Breckenridge Mountain portion has been elevated. The Kern Canyon fault is traceable for some 50 miles through the southward-trending portion of Kern Canyon and along the eastern base of Breckenridge Mountain; it then disappears south of Walker Basin into an area of low, even-crested mountains.

The mountains of the southern Sierra Nevada, made up of a basement complex of granitic and metamorphic rocks, slope gently westward to the San Joaquin Valley foothills, where the basement complex is covered by Tertiary sedimentary rocks. The surface of the basement and the overlying sediments exposed along the foothills slope westward under the San Joaquin Valley at a more or less uniform angle of 6°. The foothills are broken by many small normal and vertical faults trending from north to west. The exposures of Tertiary sediments, continuous for some 25 miles along the foothills, are abruptly terminated on the south by the Edison fault which brings up the basement complex south of lower Caliente Canyon.

A short distance southeast of lower Caliente Canyon, just south of the quadrangle mapped, the San Joaquin Valley foothills abut against a steep, northwest-sloping front that rises abruptly to a mountain plateau. The plateau reaches a high point of nearly 7,000 feet at Bear Mountain, and owes its existence to elevation along the White Wolf fault bounding its straight northwestern base. About 20 miles farther southeast, this fault is paralleled by the northeast-trending Garlock fault, an active vertical master fault of left-lateral movement.

PHYSIOGRAPHY

Most of the area in Breckenridge Mountain quadrangle is plateau-like; the hills and mountains rise gradually northeastward, with relief ranging from 650 feet elevation in the extreme southwest corner to 7,544 feet at Breckenridge Mountain, the highest point. From San Joaquin Valley the terrain rises gradually north of east, through low foothills at the western border of the quadrangle, to high, plateau-topped mountains in the eastern portion, except for local irregularities due to faulting. All major streams are consequent to this general slope and flow south of west. The mountains throughout the quadrangle are characterized by subdued summits and gently sloping flanks. However, the major streams and their main tributaries are deeply incised in narrow V-shaped canyons. Those such as Kern River, Walker Basin Creek, and Caliente Creek have deepened their channels about 1,500 or 2,000 feet below the gently rolling upland surface. Of these, Caliente Creek has developed a small flood plain where it emerges through the low foothills.

The flat mountain summits and the foothills to which they taper, are remnants of an earlier erosion surface which had reached the late maturity stage of the first cycle of erosion. Subsequent elevation by westward tilt has caused dissection of this old surface and rejuvenation of the canyons so that the area is now in the late youth or early maturity stage of the second cycle of erosion.

Drainage. Kern River flows southwestward through a deep, youthful gorge across the northwest corner of the quadrangle. Cottonwood Creek drains the southwestern slope of Breckenridge Mountain and flows southwest through a deep canyon in the lower reaches. Walker Basin Creek drains the valley of that name and flows southwest through a narrow gorge into Caliente Creek at Bena. Caliente Creek flows westward through a narrow canyon, is joined at Caliente by Tehachapi Creek flowing northwest, and finally opens out through a flood plain at Bena into San Joaquin Valley.

Physiographic Features. Breckenridge Mountain, which covers the north-central portion of the mapped quadrangle, is roughly a dome-shaped mountain that has a steep, abrupt eastern slope facing Walker Basin. The imposing straight eastern front of this mountain is a fault escarpment; it rises from an elevation of 3,500 feet at the eastern base to a high point of 7,544 feet at Breckenridge Mountain within a distance of about 2 miles. The top of the mountain mass is a gently rolling plateau averaging 6,500 feet elevation, which slopes southwestward to a much lower area of mountains at elevations of 3,000 feet to 4,500 feet. The lower plateau slopes very gradually over a distance of about 6 miles down to about 2,500 feet at its southwestern margin, beyond which are low foothills made up of easily eroded sediments.

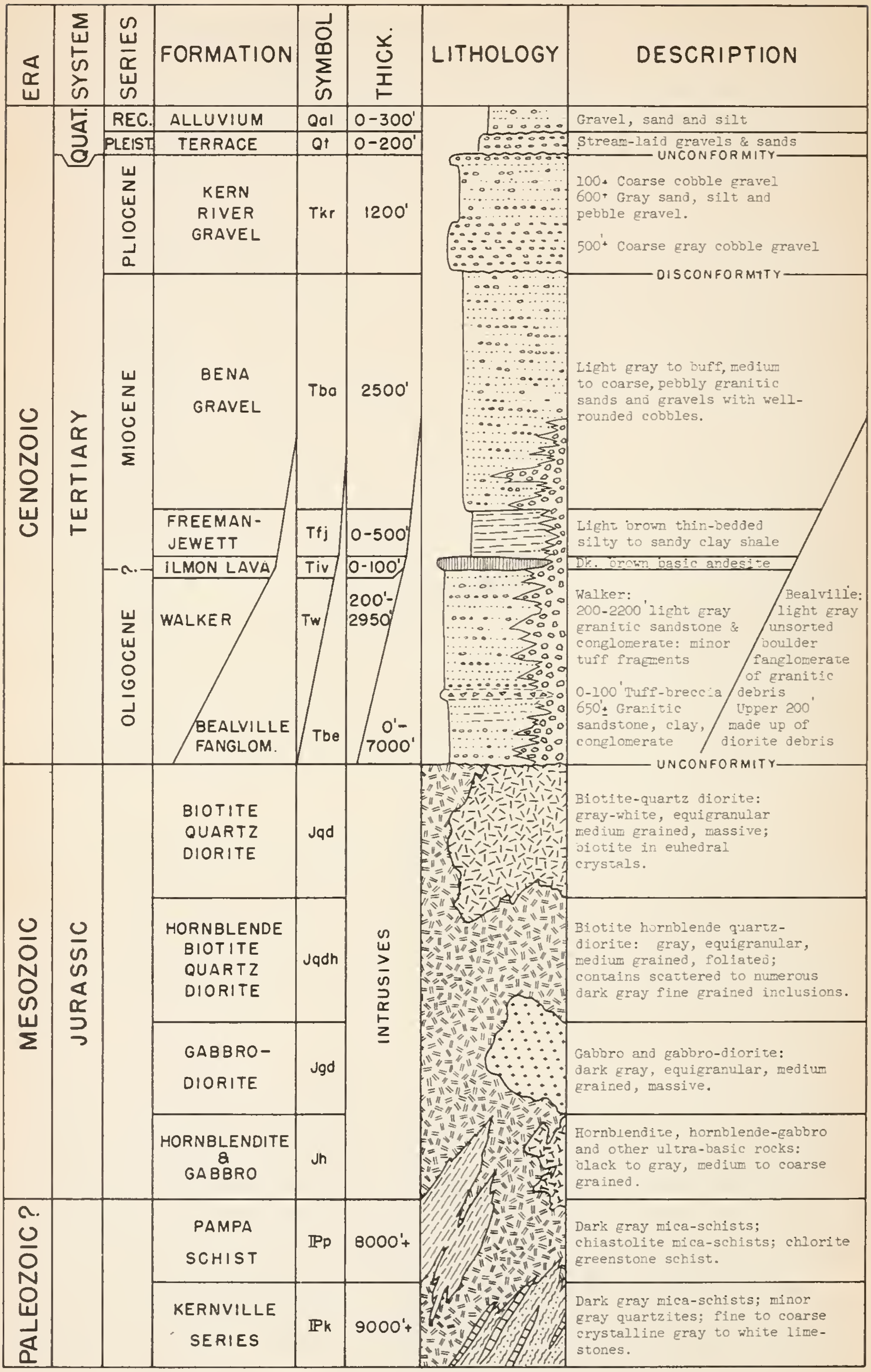

FIGURE 2. Columnar section, Breckenridge Mountain quadrangle.

The area east of the Breckenridge Mountain plateau is part of the block depressed along the Kern Canyon fault zone. Red Mountain is the westernmost spur of Piute Mountain, a northwest-trending mountain range about 8,000 feet high lying east of the mapped quadrangle. Red Mountain is separated from Breckenridge Mountain by 4,300-foot high Havilah Pass. South of this pass lies Walker Basin, a triangular alluviated valley about 3,500 feet in elevation. This valley is the lower portion of a major canyon draining westward from Piute Mountain, and has become dammed by uplift of the Breckenridge Mountain block on the west causing the canyon to become filled with alluvium to form a valley. This valley drains southwestward through Walker Basin Creek, an antecedent stream which has eroded deeply into the mountain block during its elevation. The mountains of the southeastern portion of the quadrangle mapped are an extension of the Breckenridge Mountain plateau; they continue eastward south of Walker Basin. This mountainous area is divided into two main east-west trending ridges by Caliente Canyon; the ridges are characterized by subdued, even-crested summits tapering from 5,000 feet elevation westward to about 2,500 feet, and dropping off somewhat abruptly to the low foothills west of Caliente.

The low, subdued topography of the foothills of the southwestern portion of the quadrangle is due largely to the underlying soft sedimentary formations which are more easily eroded than the granitic and metamorphic rocks of the mountain areas. Nearly all streams draining through these foothills have developed flood plains. The foothills slope gently into San Joaquin Valley.

STRATIGRAPHY

Pre-Cretaceous Rocks

Kernville Series

Definition. The name Kernville was proposed by Miller (1931, p. 335), for the metasedimentary series cropping out in the vicinity of Kernville. This series exposed in Kernville quadrangle was mapped as the Kernville series by Miller and Webb (1940, map). In eastern Breckenridge Mountain quadrangle, metasediments identical to the Kernville series are exposed and are mapped as such.

Distribution and Thickness. In Breckenridge Mountain quadrangle the metasediments recognized as the Kernville series crop out near the eastern border as a continuous band about a mile wide within granitic rocks on the west slope of Red Mountain. The band passes out of the quadrangle east of Walker Basin, but swings back in south of Caliente Creek and extends up Devil Canyon where it fingers southward into many linear inclusions within the invading granitic rocks. The metasediments in this band are more or less vertical and a total apparent thickness of about 6,000 feet is exposed—if not isoclinally folded.

Lithologic Character. The Kernville series exposed in Breckenridge Mountain quadrangle is made up largely of mica schist, some interbedded quartzite, and lenses of crystalline limestone. The mica schist is dark gray, weathers brown-gray, laminated, fine-grained, and has prominent cleavage. It becomes medium- to coarse-grained adjacent to granitic intrusions. The schist is made up largely of biotite, but has some muscovite, feldspar, and quartz. Microscopically, the schist of the Kernville series

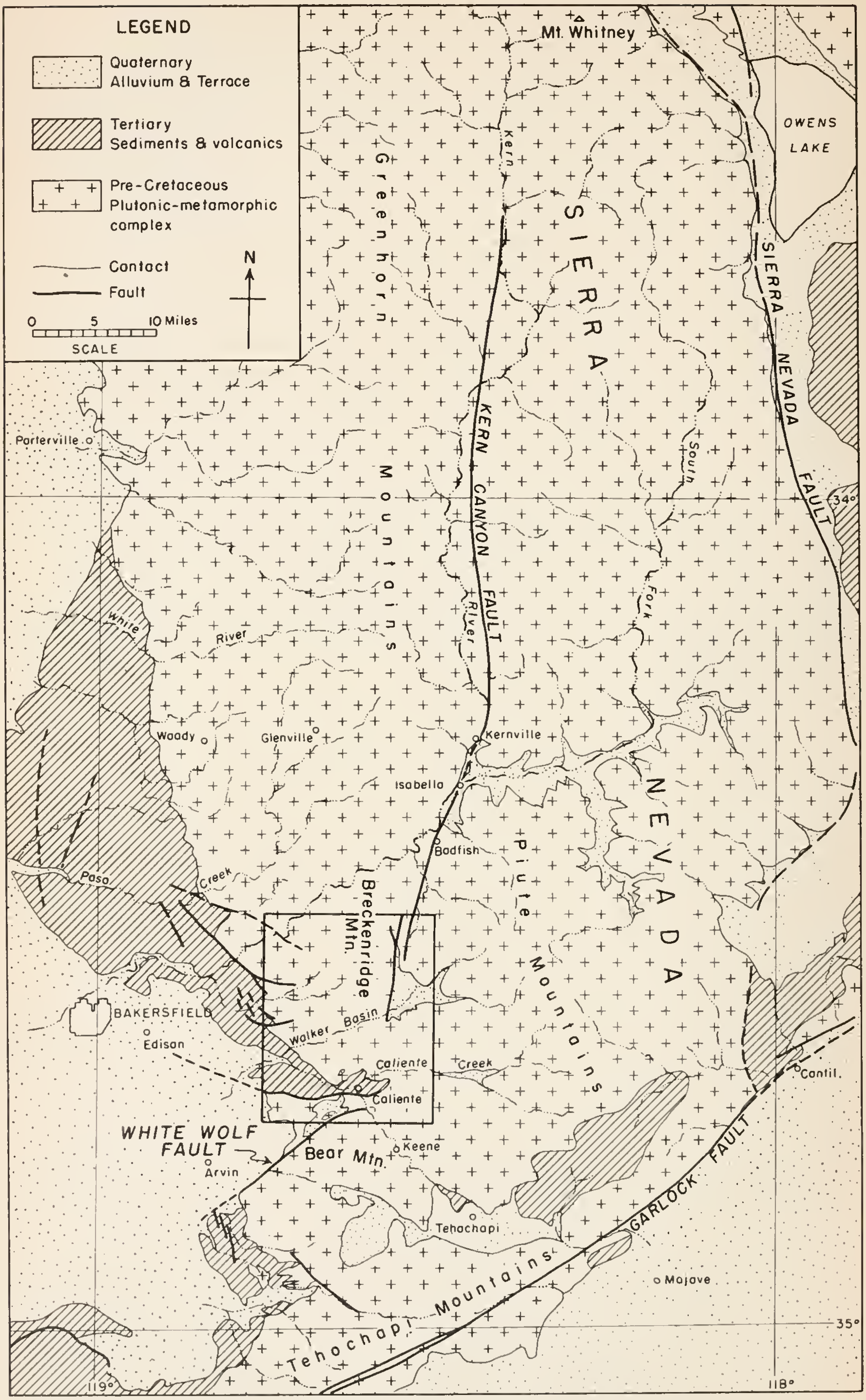

FIGURE 3. Geologic map of the southern Sierra Nevada showing location of Breckenridge quadrangle.

has a crystalloblastic fabric developed through recrystallization of a pelitic sediment under processes of regional metamorphism. It is quite uniform in composition and texture, and consists essentially of quartz, biotite, muscovite, albite, and garnet. Quartz is one of the most abundant minerals and occurs in aggregates of equidimensional and elongate grains that include needle-like crystals and plates of muscovite. Dark brown, strongly pleochroic biotite in well-oriented plates is also an important constituent of the schist. Inclusions of zircon with dark pleochroic halos are common in the biotite. Muscovite occurs in two distinct sizes: (1) as fairly large porphyroblasts up to 7 millimeters in width and (2) as small wisp-like plates and flakes less than one millimeter in diameter. Calcic albite (An_4 to An_8) is well developed in multiple-twinned equidimensional grains. Garnet occurs in rounded colorless crystals scattered at random throughout the sections, but is not an important mineral in the schist. Quartzite beds are light-gray to bluish-gray, fine-grained, and occur as interbeds as much as a foot thick.

FIGURE 4. Kernville series toward northeast. About a mile and a half northeast of Tungsten Chief mill. Quartz diorite (?) in background.

Quartzite interbeds are subordinate to the schists, but in some layers they form prominent, though much broken, outcrops. In thin section the quartzite was found to be made up of a granoblastic aggregate of quartz, albite, zoisite, hornblende, muscovite, scheelite, and graphite. Quartz, the most abundant constituent, forms rounded and elongated grains whose boundaries are both curved and sutured. Strain shadows are well developed and serve as an aid in distinguishing quartz from albite, most of which is untwinned. Hornblende is pale green in color and forms

FIGURE 5. Limestone member of Kernville series. About a mile northeast of Tungsten Chief mill.

needle-like crystals scattered throughout the sections. Small, angular grains of colorless zoisite occupy interstices. Feathery crystals and wisps of muscovite are wrapped around quartz and albite. The albite is in equidimensional grains. Scheelite, in brown idioblastic crystals, shows well-developed crystallographic outline. Scattered throughout the sections are numerous small dustlike particles of graphite.

Limestone, which crops out prominently, occurs as lenses up to 100 feet thick, some of which are traceable for about a mile. The limestone is light-gray, fine-grained, bedded, but may be white coarsely crystalline marble, depending on the degree of metamorphism. North of Walker Basin contact metamorphic action between granitic dikes and impure limestone of the Kernville series has resulted in the formation of lime-silicate rocks composed of coarsely crystalline calcite, light-reddish and brown garnet, quartz, clinozoisite, and minor amounts of scheelite.

Thin sections prepared from hand specimens taken from several zones of lime-silicate rocks indicate an assemblage of minerals which includes diopside, clinozoisite, garnet, oligoclase, hornblende, sphene, calcite, scheelite, and quartz. Clinozoisite, diopside, sphene and garnet are by far the most abundant minerals present, whereas scheelite, hornblende, and oligoclase are only locally developed. Calcite and quartz are very sporadic in their distribution and appear to have developed somewhat later than the other constituents excepting the scheelite which was one of the last minerals to form. Garnet is colorless and occurs both as idioblastic crystals and as irregular grains in granoblastic aggregates. Clinozoisite in irregular grains exhibits strong anomalous interference colors in shades of brown and blue. Diopside occurs in rounded colorless grains. Calcic oligoclase, also in rounded grains, shows several types of twinning. Sphene is rather abundant as irregular crystals. Scheelite is pale brown in color and forms idioblastic crystals and rounded grains.

FIGURE 6. Garnet and garnetized limestone zones in Kernville series. About a mile northeast of Tungsten Chief mill.

Small isolated inclusions of coarse quartz-mica schist approaching the texture of gneiss occur throughout the granitic rocks in much of the quadrangle, especially in the southeastern portion, where they have a prevailing north strike parallel to the Kernville exposures at the eastern border. They are undoubtedly incompletely digested remnants of the Kernville series as shown by a limestone inclusion about a mile long southwest of Montgomery Canyon. These widespread inclusions of uniform attitude suggest that prior to the granitic invasion the Kernville series within the quadrangle was of tremendous thickness—if not isoclinally folded.

Age and Correlation. Very little is known concerning the age of the Kernville series as it has yielded no fossils. Miller and Webb (1940, p. 352), are of the opinion the Kernville series correlates with the Calaveras

FIGURE 7. Kernville schist. One mile northeast of Tungsten Chief mill.

of Carboniferous age on the basis of lithologic similarity; and for this reason the series is tentatively assigned to the Carboniferous.

Pampa Schist

Definition. In the western part of Breckenridge Mountain quadrangle several isolated pendants of dark mica schist are prominently exposed in the Cottonwood Canyon drainage area west of Pampa Peak, for which the schist is named. The formation is possibly a phase of the Kernville series, but as it is of somewhat different lithology and as its relationship to the Kernville is obscured by granitic invasions, the Pampa is designated by a local name.

Distribution and Thickness. The Pampa schist crops out within granitic rocks as linear inclusions with vertical or near-vertical attitudes. One of these inclusions, prominently exposed west of Pampa Peak is about a half mile wide and trends northeast for about 2 miles. To the north in Cottonwood Canyon, there is a large S-shaped inclusion, half a mile to a mile wide, that is traceable for five miles. To the northeast in upper Cottonwood Canyon a linear band as much as 2 miles wide trends northwestward for about 4 miles. In addition to these three large inclusions there are many small lenticular outcrops.

All inclusions of the Pampa schist are more or less parallel with a regional northwestward trend except for the S-shaped flexure in Cottonwood Canyon. Attitudes are vertical or nearly so. The Pampa schist appears to be remnants of a once very thick, upturned section invaded

FIGURE 8. Chiastolite schist of Pampa series, two miles west of Pampa Peak.

by plutonic rocks. It is not known which side is top or bottom, but in the flexured inclusion the schist generally dips steeply toward the south and southwest, suggesting the oldest beds are to the northeast in upper Cottonwood Canyon and the youngest may be those west of Pampa Peak. If these inclusions are parts of a once continuous section not repeated by isoclinal folding, the total thickness represented must have been in the neighborhood of 20,000 feet.

Lithologic Character. The Pampa schist is generally similar to the Kernville schist in the eastern portion of the quadrangle. The Pampa schist is generally laminated and highly cleavable with platy fracture. The schist forms dark, jagged outcrops, and commonly shows minute contortions near granitic intrusions: It is made up largely of muscovite but contains some biotite, feldspar, and quartz. It is probably of sedimentary origin as suggested by its foliation, which is parallel to the original bedding. In contrast to the Kernville series, the Pampa schist contains no limestone, and quartzite is rare.

The most westerly portion of the Pampa schist exposure west of Pampa Peak is made up of chiastolite or andalusite schist, which forms a member of about 2,000 feet exposed thickness that is traceable for three-quarters of a mile. The member again appears about 2 miles northwest in Cottonwood Creek. The andalusite schist is the same as the usual Pampa mica schist, but contains numerous crystals of andalusite (chiastolite) from an eighth to a quarter of an inch thick and up to several inches long.

FIGURE 9. Chiastolite schist of Pampa series, two miles west of Pampa Peak.

They are oriented parallel to the cleavage, and have apparently resulted from an excess of alumina in this member.

In the field and in samples under the microscope one can easily distinguish the three Pampa schist units: (1) quartz-biotite schist, (2) quartz-biotite-andalusite schist, and (3) chlorite schist. The first two rocks are products of regional metamorphism of pelitic sediments in the biotite zone, and the chlorite schist might very well have been formed from either a basic tuff or lava flow. Plutonic invasions have further metamorphosed these rocks, but the action merely resulted in coarsening of the grains, especially near contacts, rather than mineralogical reconstitution.

Under the microscope the quartz-biotite schist shows a well-developed foliated fabric. Quartz is rather abundant and occurs in rounded equidimensional grains showing wavy extinction. Biotite that is dark brown in color, strongly pleochroic in shades of dark and light brown, occurs in single plates evenly distributed and as clusters of smaller crystals. Enclosed in the biotite are small crystals of zircon with dark pleochroic halos. Calcic oligoclase occurs in equidimensional grains with irregular boundaries. It is found locally only and is not an important constituent. Muscovite is unevenly distributed throughout the sections as large porphyroblastic plates that exhibit no particular orientation and as aggregates of small shredlike plates and wisps that form swirls around the quartz grains.

Under the microscope the quartz-biotite-andalusite-muscovite schist, too, shows a well-developed foliated fabric with large porphyroblasts of

FIGURE 10. View northeast toward Breckenridge Mountain. Kern River beds exposed in hills to left; Pampa schist and quartz diorite in dark rugged hills to right. Pampa Peak near extreme right.

andalusite (chiastolite) set in foliated matrix or quartz, garnet, plagioclase, and mica. Quartz is very abundant, forming rounded equidimensional grains scattered throughout the sections and granoblastic aggregates of coarse grains lying between the broken ends of large andalusite crystals. Biotite also is abundant, occurring in dark greenish-brown idioblastic plates that exhibit strong pleochroism in shades of dark and light brown. Inclusions of zircon are common, many of them are surrounded by dark pleochroic halos. Andalusite, called chiastolite because of its symmetrically arranged carbonaceous inclusions, is colorless; it occurs in porphyroblasts as much as 2 inches in length, and as irregular or skeletal crystals having a motheaten appearance. In places the andalusite has the appearance of having been replaced in part by quartz, and it is not uncommon to find plates of muscovite forming incomplete rims around the andalusite crystals. Muscovite is quite common and forms colorless plates scattered throughout the sections and also somewhat coarser plates associated with the coarse-grained quartz between the broken ends of the andalusite crystals. Both garnet and calcic oligoclase are present as angular and rounded grains.

The northeastern exposure of the Pampa schist contains a massive chlorite schist a member about 2,000 feet thick that is exposed between Rattlesnake and South Fork Cottonwood Creeks. The member is made up of fine grained, massive, greenish-brown rock with irregular fracture rarely showing cleavage. It is essentially a "greenstone", but appears to be made up of finely divided chlorite. Locally it contains veinlets of calcite and quartz. The member is apparently of volcanic origin, probably a basalt, but is highly altered.

Age and Correlation. As the Pampa schist has yielded no fossils, its age is unknown. Its relationship to the Kernville is unknown. All that can be said is that it is Jurassic or older.

Intrusive Rocks

Plutonic intrusive rocks characteristic of the Sierra Nevada batholith underlie the greater portion of Breckenridge Mountain quadrangle in which the major rock type is quartz diorite. The following types of intrusive rocks were recognized and mapped: quartz diorite, divided into two distinct facies—(a) foliated hornblende-biotite quartz diorite; and (b) massive biotite quartz diorite; gabbro and gabbro-diorite; hornblendite, hornblende diorite and other basic rocks, including small bodies of gabbro-norite that were examined both in the field and in the laboratory.

The quartz diorite forms the major portion of the Sierra Nevada granitic batholith within the quadrangle; the basic rock types form local intrusions or segregates only. All of these intrusives are intimately associated and part of the Sierra Nevada batholith invasion is believed to have occurred in very late Jurassic time.

Hornblende-Biotite Quartz Diorite

Hornblende-biotite quartz diorite, more or less foliated, is the most widespread facies of the quartz diorite in Breckenridge Mountain quadrangle. The rock is widespread throughout the northern portion of the quadrangle, and extends into the southeastern portion of the quadrangle.

Lithologic Character. The foliated hornblende-biotite quartz diorite is an equigranular, light- to medium-gray rock, depending on the amount of hornblende. It is made up largely of white feldspar and quartz in the average ratio of about 3:1. Biotite and hornblende are always present, but in varying amounts. The dark minerals range from less than 5 percent to about 30 percent of the total mineral content of the rock. The biotite occurs as small scattered flakes, and the hornblende as elongated crystals somewhat larger than the other minerals of the rock.

Throughout the entire quadrangle where this rock is well exposed it exhibits remarkably uniform texture and mineralogical composition, excepting locally where small inclusions of a finer-grained texture and an increase in the mafic constituents have developed.

In thin section the hornblende-biotite quartz diorite has a hypidiomorphic granular texture. Both the biotite and hornblende show several crystal faces, but the feldspar and quartz are usually anhedral. The plagioclase is sodic to intermediate andesine (An_{35} to An_{43}) and makes up from 45 to 50 percent of the rock by volume. It shows well-developed complex twinning and in some places a light zoning with only a minor difference in composition between the zones. Alteration is not marked, usually to sericite and rarely to kaolin. Quartz is common and averages between 15 and 20 percent of the rock by volume; it exhibits strong wavy extinction. Hornblende makes up about 20 percent of the rock by volume, but locally it is either in smaller or greater amounts. It is dark brownish-green to green in color and moderately pleochroic in shades of green, greenish-brown, and bluish-green. Twinning on the (100) is rare.

FIGURE 11. Quartz diorite with pegmatite dike. Caliente Canyon at intersection of Walker Basin road.

Biotite usually in dark brown pleochroic plates makes up to 10 percent of the rock by volume. Inclusions of magnetite and zircon are common in the biotite, more so than in the hornblende. Locally a small amount of colorless diopside occurs, especially as cores surounded by light green fibrous amphibole. Minor accessory minerals are zircon with dark pleochroic halos in biotite, sphene, allanite, apatite, and magnetite. Calcite, kaolin, sericite, and chlorite are the secondary minerals.

The hornblende-biotite quartz diorite is characterized by primary foliation almost throughout which is most prominent in the darker phases rich in biotite and hornblende, and poorest or almost absent in the lighter phases. In some areas it is so prominent as to give the rock the appearance of gneiss, but the rock is of more or less homogeneous granular texture rather than being composed of alternating layers of varying mineralogical content such as characterize true gneiss. The foliation is generally developed by sub-parallel orientation of mineral grains in a homogeneous mass. The rock weathers by mechanical disintegration and by exfoliation, and has a tendency to joint or cleave parallel to the foliation.

The hornblende-biotite quartz diorite commonly contains inclusions or xenoliths of dark fine-textured dioritic rock in amounts varying from almost none to 20 percent of the enclosing rock. They occur as lenses of all sizes, but average about 8 inches across and about 2 inches thick. They are invariably oriented parallel to the foliation of the host rock. These inclusions are probably partially digested remnants of the original metasediments intruded by the hornblende-biotite quartz diorite.

FIGURE 12. Quartz diorite with dikes and inclusions. Up Oiler Canyon a mile from Caliente Canyon.

Biotite Quartz Diorite

The massive biotite quartz diorite almost devoid of hornblende comprises the lighter-colored phase of the quartz diorite and forms several bodies within the mapped quadrangle. The largest mass occurs in the central portion in the vicinity of lower Walker Basin Canyon. Masses also occur north of Mount Adelaide, at Red Mountain in the extreme northeastern portion of the quadrangle, in the Piute Mountain range to the east, and in the extreme southwestern portion of the quadrangle. To the north, in Kernville quadrangle, the rock was mapped as the Isabella granodiorite by Miller and Webb (1940, p. 357), although in a footnote they state it to be quartz monzonite on the basis of petrographic determinations.

Lithologic Character. The biotite quartz diorite is gray-white, medium- to coarse-textured and equigranular. It is massive and rarely shows foliation. The rock is made up of white feldspar (mainly plagioclase) and translucent quartz in the average ratio of about 2:1. Dark minerals which make up less than 25 percent of the total rock mass consist of biotite in euhedral hexagonal crystals ranging from an eighth to nearly half an inch across. Hornblende and other dark minerals are either absent or occur in very small amounts.

Microscopically the biotite quartz diorite has a hypidiomorphic granular texture. The plagioclase is sodic andesine (An_{32} to An_{36}) which makes up to 46 percent by volume of the rock. The mineral is complexly twinned and some grains show poorly defined zonal structure with only a slight difference in composition between the successive zones. Locally the andesine is altered to sericite, more so at the center of each crystal than at the margin or outer zone. Minor amounts of microcline are present, especially in those specimens collected from the quartz diorite exposed in the northeastern part of the quadrangle. Quartz is usually in rounded grains in amounts up to 25 percent. Biotite is the commonest mafic mineral present, although hornblende is locally present and in a few isolated occurrences it exceeds the biotite in amount. The biotite is in dark brown to olive-green plates that show strong pleochroism in shades of brownish-green. In a few sections it is altered to pale green chlorite. Hornblende, when present, is in bluish-green stumpy prismatic crystals. Minor accessory minerals include brown tourmaline, sphene, apatite, magnetite, and zircon with dark pleochroic halos. Chlorite, sericite, and calcite are secondary minerals.

In Kernville quadrangle, according to Miller and Webb (1940, p. 357), the "Isabella grandiorite" averages the following percentage composition: quartz, 30; orthoclase or microcline, 30; plagioclase (oligoclase-andesine An_{30}-An_{40}), 30; accessory minerals, 10. The authors (footnote, p. 357), state this quartz monzonite to be the most common facies. However, in samples taken in Breckenridge Mountain quadrangle from similar-appearing rock, there is less than 5 percent total potash feldspar, well above 45 percent plagioclase and as much as 25 percent quartz, a composition characteristic of quartz diorite. Although the massive biotite quartz diorite is probably a facies of the foliated hornblende quartz

FIGURE 13. Inclusions and faulted pegmatites in hornblende quartz diorite. Up Oiler Canyon four miles north of Caliente Canyon.

FIGURE 14. Inclusions in quartz diorite in Kern River Canyon about a mile downstream from mouth of Cow Flat Creek.

diorite and is about the same mineralogical composition except for the near absence of hornblende, it is fairly distinct and can be mapped as a unit. Contacts between the two facies are sharp in some areas; in others they are imperceptibly gradational. The two facies are distinguished from each other by the massive character of the biotite quartz diorite facies, also by its lighter color, scarcity of hornblende, euhedral character of the biotite, and absence of inclusions and of foliation.

Jointing in the massive quartz diorite is widely and more or less evenly spaced. South of Pampa Peak two major sets are developed, one trending N. 50° W. and dipping steeply NE, and another at right angles to this set and generally vertical. The rock weathers readily by mechanical separation of grains in softer portions and by exfoliation of harder portions into round outcrops and boulders.

Mode of Intrusion. The foliated hornblende-biotite quartz diorite and massive biotite quartz diorite are believed to represent two waves of the Sierran batholithic invasion in this local area, as indicated by the difference of the two facies and by the occurrence of many pegmatite dikes bordering the central mass of massive biotite quartz diorite which appear to have originated from it. The foliated hornblende-biotite quartz diorite is the older of the two facies and appears to have invaded the metasediments by gradual emplacement *lit par lit.* The massive biotite quartz diorite is younger, representing the later and final stage of the Sierran invasion by massive intrusion of liquid magma.

FIGURE 15. Inclusions in quartz diorite in Kern River Canyon about a mile downstream from mouth of Cow Flat Creek.

The manner in which the foliated hornblende-biotite quartz diorite invaded the metasediments is well shown in all exposures where they occur as tabular remnants fingering out into the intrusive rock. This condition clearly indicates that the magma invaded the metasediments accordantly along bedding planes, metamorphosing and digesting them bed by bed. Many inclusions of these metasediments remained in place as incompletely digested remnants within the quartz diorite. The planar foliation of the quartz diorite, which is consistently accordant to the attitude of the unassimilated remnants of the metasediments, is probably flow-structure, developed by flowage of the magma as it worked up along bedding planes of the metasediments and assimilated those rocks bed by bed. The foliation of the plutonic rock is thus of primary origin and its attitude is relict to that of the original metasediments it invaded; it indicates that the rock may have been emplaced as a series of sill-like intrusions by slow, gradual assimilation of the metasediments bed by bed.

The local gradation of the foliated quartz diorite into the massive quartz diorite indicates that the two magmas in part were intruded simultaneously while the occurrence of the massive quartz diorite as irregular bodies within the foliated quartz diorite indicates the massive quartz diorite to be later, in part. The massive biotite quartz diorite intruded the pre-existing rocks as a large mass of fluid magma cutting through both the metasediments and the earlier, perhaps incompletely solidified, foliated quartz diorite, and completely digested the rocks it intruded. The manner in which the massive quartz diorite has intruded the metasediments is superbly shown by field relationships at Red Mountain, and also west of Pampa Peak. In these areas the quartz diorite was intruded as a series of dikes fingering into the bedding of the metasediments generally accordant to the bedding but with some dikes slightly discordant to it. Some dikes can be seen to intersect or merge with each other.

Gabbro and Gabbro-Diorite

Two exposures of dark-colored gabbro and gabbro-diorite occur within quartz diorite in the northwestern portion of Breckenridge Mountain quadrangle. One of these occurs as an irregular body in Kern Canyon near the extreme northwest corner of the map. The other occurs as a linear body near Pampa Peak and extends northeastward for some 4 miles.

The gabbro is a massive dark-colored, medium-grained equigranular rock. It is gray-black on a fresh surface but weathers gray and does not disintegrate mechanically but tends to exfoliate into round boulders. The rock is made up of about 50 percent dark to medium-gray plagioclase feldspar, the remainder being composed of hornblende, pyroxene, and biotite. The rock varies from gabbro to gabbro-diorite depending on the percentage of calcic and sodic plagioclases.

Under the microscope the hornblende gabbro-diorite is a medium- to coarse-grained rock with a hypautomorphic granular texture. Individual crystals are usually less than 5 millimeters in diameter, although locally the rock is coarser grained. The feldspar, sodic labradorite (An_{48} to

FIGURE 16. Faulted pegmatite dikes in dark gabbro-diorite near Richbar, Kern River Canyon.

An_{56}), constitutes at least 40 to 50 percent of the rock by volume and occurs in subhedral crystals showing complex twinning and poorly defined zoning. Secondary alteration of the feldspar is not common, but when present it is to a cloudy zone of sericite flakes usually at the central part of the crystal. Augite is present in pale greenish subhedral crystals that show weak pleochroism. Twinning is common and so is alteration to a pale greenish amphibole. Augite, although somewhat sporadic in its distribution, constitutes at least 20 percent of the rock by volume. Hornblende is strongly pleochroic from pale yellowish to brownish-green, and forms irregularly shaped prisms, commonly twinned. It appears to be in part an alteration product of the augite and makes up about 25 percent of the rock by volume. Locally small amounts of dark brown biotite and rounded quartz are present. Magnetite and zircon are generally inclusions in the hornblende. Apatite and sphene occur as well shaped crystals with random orientation.

In thin sections the gabbro is seen to be a coarse grained rock with an average grain size of about 5 millimeters. The rock is composed of labradorite (50 percent), hornblende (30 percent), hypersthene (15 percent), biotite (5 percent), and minor amounts of quartz. The feldspar, sodic labradorite (An_{52} to An_{56}), forms well twinned crystals showing multiple twins according to the albite, pericline, and carlsbad laws. The twinning lamellae in a few of the labradorite crystals are bent sufficiently to suggest minor post-feldspar deformation. Zoning is present but not distinctly enough to determine differences in zone composition. The hornblende is pleochroic in shades of light green and pale brown and forms fairly large irregular prisms measuring as much as 10 millimeters in length. Hypersthene is present in rounded crystals, generally as cores surrounded by pale green to colorless amphibole. The hypersthene is slightly pleochroic from pale pink to pale green and contains schiller inclusions. Biotite forms dark golden brown subhedral crystals, and quartz, although generally present in small amounts, forms rounded grains. Zircon, magnetite, and apatite are present in small amounts.

Several small bodies of gabbro-norite were found along the road between Bakersfield and Breckenridge Mountain about 1 mile northeast of Hoosier Flat. The weathered surface of this rock is pitted due to the almost complete removal of the feldspar through weathering. In addition, the rock is generally stained dark greenish brown from iron oxides released upon weathering of the mafic minerals. The average gabbro-norite is a coarse-grained rock containing about 50 percent labradorite, 15 percent hypersthene, and diopside, 15 percent olivine, 10 percent hornblende, 5 percent spinel, and about 5 percent apatite, sphene, magnetite, and ilmenite. The feldspar is calcic labradorite (An_{60} to An_{68}) and forms large irregular and rounded crystals showing multiple twinning. It includes poikilitically rounded crystals of pale greenish diopside and is surrounded in places by a rim also composed of diopside. Both hypersthene and diopside are present, but with an excess of hypersthene over diopside. The hypersthene forms rounded and irregular crystals showing weak pleochroism from pale pink to pale green. Schiller structure is well developed, especially in the larger crystals where one can see the arrangement of thin plates of reddish-brown hematite in parallel lines. The diopside is in pale green rounded crystals. Olivine occurs in fairly well formed crystals that have been somewhat rounded by magmatic corro-

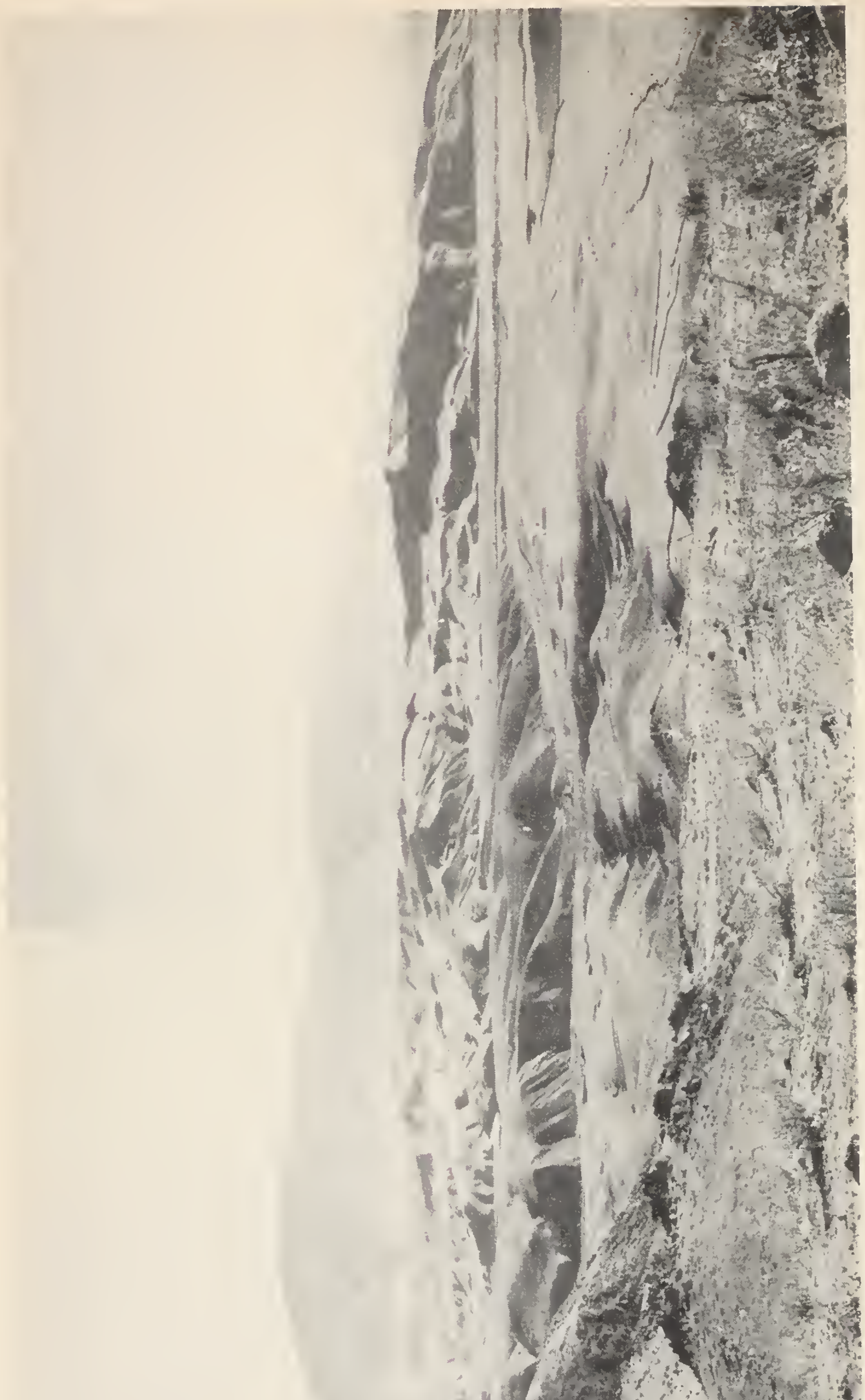

FIGURE 17. View south across mouth of Caliente Canyon. Quartz diorite in foreground; Walker in low slopes just beyond; Bena and Kern River gravels on ridge beyond wash. Scarp of White Wolf fault in background.

sion. Surrounding many of the olivine crystals are two zones of which the first is colorless amphibole, and outer or second is a myrmekitic intergrowth of labradorite and pale green amphibole. In one thin section several rounded olivine crystals were found surrounded by a rim of granular pale green amphibole and bleb-like grains of dark green spinel. The amphibole is pale bluish-green hornblende in the form of irregular prisms and needle-like crystals. Dark green spinel is common. It forms myrmekitic intergrowths with the hornblende and also occurs as inclusions in the feldspar. Zircon, sphene, apatite, and magnetite are rare.

Mode of Intrusion. The relationship of the gabbro to the enclosing quartz diorite is not definitely known, but it appears to grade into the quartz diorite in most places thus making the contact difficult to map. However, in other places, notably the west side of the exposure in Kern Canyon, it appears to be cut by numerous stringers of quartz diorite. The gabbro and gabbro-diorite are therefore probably in part segregates of the quartz diorite and were probably in part somewhat earlier. They may represent local basic intrusions during the early stage of the Sierran invasion.

Hornblendite and Other Basic Rocks

Small irregular and linear masses of coarse crystalline hornblendite, hornblende diorite, and other basic rocks occur within quartz diorite mainly in the southwestern portion of the quadrangle near Beale Hill. Another crops out north of Pampa Peak, and another north of Rankin Ranch on the west side of Walker Basin. The largest exposure which covers a quarter of a square mile occurs a mile northwest of Beale Hill; others are much smaller.

The hornblendite and other basic rocks are extremely variable both as to texture and mineral content. The most common type is coarsely crystalline black hornblendite made up of bladed hornblende crystals ranging from a quarter of an inch to over an inch in length. Microscopically the hornblendite is composed almost wholly of hornblende with only a minor amount of andesine and secondary clinozoisite. The hornblende is greenish-brown in color and shows weak pleochroic colors in shades of pale green and brown. In several sections there appears to be at least two distinct forms of hornblende: (1) light green hornblende which is unaltered and (2) pale brown to colorless hornblende that is more or less altered to clinozoisite. Anthophyllite is also present in small amounts. Sodic andesine (An_{36}) occurs in small rounded crystals partially altered to sericite.

Occurring in the hornblendite are several dikelike bodies composed almost wholly of coarse-grained oligoclase here referred to as leucodiorite (Johannsen, 1937). These bodies of leucodiorite do not appear to represent direct crystallization from the magma, but because of their cross-cutting relationships to the hornblendite and anthophyllite veins, and their sharp contacts, they seem to represent intrusions at a later stage in the igneous cycle (Anderson, 1933).

In thin section the leucodiorite has a hypautomorphic granular texture. The important feldspar is calcic oligoclase (An_{24} to An_{26}), which forms large, partially altered anhedral crystals that show both albite and carlsbad twins. Enclosed within the larger oligoclase crystals are small rounded grains of fresh untwinned albite. A few pale green prismatic crystals of hornblende may be found as well as a small amount of colorless muscovite. Leucodiorite varies to hornblende diorite made up of coarse crystalline hornblende and white plagioclase in about equal amounts.

In thin section the hornblende diorite has a hypidimorphic granular texture and is composed of plagioclase and hornblende in approximately equal amounts. The feldspar, sodic andesine (An_{38}), forms anhedral crystals that show complex twins and no zoning. Secondary alteration to sericite is common. Hornblende is pale brownish in color and slightly pleochroic. It forms irregular stumpy prisms with twinning parallel to the (100). Minor amounts of sphene, zircon, and magnetite are present as well as such secondary minerals as sericite, chlorite, and clinozoisite. All these rocks are massive and occur as irregular bodies. Associated with them are thin veinlike zones of greenish actinolite and anthophyllite, and irregular lenslike bodies of leucodiorite which is composed almost wholly of oligoclase. All of these basic rocks are probably segregates of the quartz diorite containing an abundance of moisture as well as magnesium and iron.

Commonly associated with the basic rocks, especially near Beale Hill and north of Rankin Ranch, are layers of banded hornblende-biotite gneiss made up of layers rich in hornblende alternating with layers containing less. The banding in these layers is accordant to the foliation of the enclosing quartz diorite. These are injection gneisses, probably local phases of the quartz diorite high in water.

Pegmatite Dikes and Quartz Veins

Dikes of granite pegmatite ranging up to 50 feet thick, are locally present in the granitic rocks; some are traceable for a mile. They are most prominently developed along the northwestern and southeastern margins of the large central mass of massive biotite quartz diorite of lower Walker Basin Canyon. The dikes appear to originate from this rock and cut the foliated hornblende-biotite quartz diorite and gabbro alike. They trend generally northeastward, more or less parallel to the margins of the massive quartz diorite, and usually dip steeply toward it. Other occurrences of pegmatite dikes are in the extreme southwest corner of the quadrangle where there are numerous parallel dikes trending northwest at the edge of the massive biotite quartz diorite. Then dikes trending northwest also occur at the edge of the quartz diorite intrusion at Red Mountain. Several pegmatites crop out on the north side of Kern Canyon in the gabbro.

The pegmatite is a coarse, very uneven-grained white rock made up of quartz and white orthoclase feldspar, and some microcline, in anhedral crystals up to an inch or so in size. Some dikes are made up almost entirely of milky quartz, others of feldspar. Small to medium-sized flakes of muscovite and biotite are commonly present. Some dikes, notably two large ones a mile west of Castro Ranch, and those on the north side of Kern Canyon, contain crystals of black tourmaline up to 2 inches long and half an inch thick.

The pegmatite dikes appear to have generated from massive biotite quartz diorite along the margins of those intrusions and to have penetrated the older plutonic rocks into which it has intruded. The pegmatites represent the latest and final stage of the Sierran invasion in this area.

Lenticular veins of pure white milky quartz up to several feet thick crop out in a number of places in the granitic rocks. They are commonly associated with the pegmatite dikes. The quartz veins are not mineralized.

FIGURE 18. Ilmon lava flow. Walker beds below. Terrace gravel on Walker to right. Caliente Wash two and a half miles east of Bena.

Tertiary System

Walker Formation

The name "Walker formation" first appeared in California literature in a paper on Mt. Poso oil field in which V. H. Wilhelm and L. W. Saunders, (1928, p. 9), described it as "a series of land-laid beds consisting of sands and shales of characteristic greenish color, made up of granitic and volcanic material, lying unconformably below Temblor Miocene and resting on granite, and penetrated by three wells where it is 375 to 594 feet in thickness." The name was again used by H. A. Godde, (1928, pp. 5-10), in the east side oil fields of Kern County, "for lower member of Temblor group; is probably lower Miocene and may be equal to Vaqueros formation, 0-1,200 feet thick, average 700 feet, unconformably underlies Temblor formation and rests unconformably on granite."

The use of the name "Walker formation" for the basal land-laid sediments of the east side oil fields of Kern County is now well established, despite the fact that the name has previously been used in American literature. However, no mention has ever been made of the derivation of the name nor has an outcrop section been described. This formation is exposed at several areas in the east side foothills from Poso Canyon southward to Caliente Canyon, and reaches its maximum development in Caliente Canyon.

Distribution and Thickness. Within Breckenridge Mountain quadrangle, the continental Walker formation crops out in lower Caliente

FIGURE 19. Walker beds exposed in cut on Highway U. S. 466, one mile west of Ilmon.

Canyon in the vicinity of the juncture with Walker Basin Creek. The section exposed along the southeast bank of Walker Basin Creek, 1 to 2 miles northeast of Bena, may be taken as the type outcrop section of the Walker formation. Here it consists of about 2,000 feet of terrestrial sandstone, conglomerate and gritty clay that rests on quartz diorite. The Walker conformably underlies the Ilmon basalt flow. Southeastward along strike, the Walker formation thickens to 2,950 feet and grades into fanglomerate mapped as the Bealville fanglomerate facies. Northwestward from the type section, the Walker thins and extends out of the quadrangle into Cottonwood Canyon. Only a few erosional remnants of the Walker occur farther up this canyon within the quadrangle where it consists of about 200 feet of gravel and sand.

Lithologic Character. The Walker formation is made up of light-gray to pinkish-gray, well-bedded, moderately indurated granitic sandstone and conglomerate. Fairly well-rounded pebbles, some of which are as much as several inches in size, consist of granitic rocks and some metamorphic rocks such as quartzite, phyllite, schist, and gneiss. Interbedded in minor amounts, are poorly bedded greenish, gritty clays up to 20 feet thick. They resemble old soils and commonly contain small, white calcareous nodules. Some clays are of a faint reddish tinge, but maroon-red beds are notably absent in the Walker. Thin layers of gray-white gritty marl are locally associated with the clays.

In the type section, the lower 650 feet of Walker formation consists of interbedded light-gray, arkosic conglomerate, sandstone and greenish clay, with pebbles made up almost entirely of granitic and metamorphic debris. This is overlain by a bed up to 100 feet thick of pinkish-gray tuff made up largely of angular fragments of white pumice and some of pink rhyolite with prominent flow structure, averaging about half an inch in size, but ranging up to 2 inches. The matrix is an ill-sorted light-gray tuffaceous sandstone. This tuff member is generally well indurated and is a marker bed traceable for nearly 4 miles in the type area, and again shows up capping the hills northwest of Caliente; a similar bed crops out 1 mile southeast of this town. The upper 1,200 feet of Walker formation overlying the tuff bed in the type section is predominantly arkosic pinkish-gray sandstone and conglomerate, made up of granitic and some metamorphic debris, and a minor admixture of tuff fragments in some layers. Thin interbeds of light reddish and green clays occur locally. Southeastward, this upper member of the Walker thickens to about 2,000 feet near Ilmon, then grades laterally along strike into the coarse Bealville fanglomerate.

In Cottonwood Canyon, the Walker formation is only about 200 feet thick and conformably underlies the Freeman-Jewett shale. The Walker here is made up largely of light-gray gravels composed of well-rounded cobbles of granite, metamorphic, and some porphyritic rocks.

Age and Correlation. Silicified fossil wood, chiefly sycamore and oak, occurs in the upper Walker beds above the tuff bed at several localities about 2 miles north and 2 miles east of Bena. Fossil leaves of broad-leaved trees have been found at one place on the south bank of Walker Creek, below the tuff bed. However the age significance of this flora is not known at this time. At one locality northeast of Bena a gastropod was found of the genus *Helix,* a land snail.

In wells drilled on the eastern margin of San Joaquin Valley, the Walker formation is found to lie above the basement complex and below the Vedder sand, which in turn underlies the Freeman-Jewett shale which carries a lower Miocene (Zemorrian) foraminiferal fauna. The continental Walker formation is thus generally believed to be of lower Miocene (Zemorrian) or Oligocene (Refugian) age, and is probably correlative with the Tecuya formation at the south end of San Joaquin Valley.

The lack of red beds in the Walker formation not only in Caliente Canyon, but throughout its areal extent in eastern San Joaquin Valley is noteworthy. All continental formations of Oligocene-lower Miocene age throughout the Coast Ranges, and those in the Mojave Desert, such as the Goler beds (Dibblee 1952) in El Paso Mountains, are made up largely of red beds. Red coloration in sediments is the result of thorough oxidation of iron salts which is believed to occur in a warm wet-and-dry climate. The Walker formation was apparently deposited under climatic conditions unfavorable for complete oxidation of iron salts so that the red coloration failed to develop. This is suggested by the color change in its correlative, the Tecuya formation, at the south end of San Joaquin Valley: the Tecuya formation consists of brilliant red and green beds west of Grapevine Canyon, but eastward the colors give way to light-gray and buff such as are characteristic of the Walker formation.

FIGURE 20. Bealville fanglomerate in cut on U. S. Highway 466, three miles south of Ilmon.

Bealville Fanglomerate

Definition. The unsorted boulder-gravel facies of both the Walker and overlying Bena formations exposed in Caliente Canyon are mapped as the Bealville fanglomerate.

Distribution and Thickness. The Bealville fanglomerate is exposed from the town of Caliente westward along the south side of Caliente Canyon into the hills 3 miles south of Bena. The type section is designated as the section exposed along the highway southward from Ilmon, where the formation consists of granitic fanglomerate that dips southward and attains a thickness of over 7,000 feet. West of this section, the Bealville fanglomerate grades laterally into both the Walker and Bena formations.

Lithologic Character. The Bealville fanglomerate in the vicinity of the type section is a light-gray loosely consolidated mass of unsorted granitic rubble made up of semi-rounded boulders of quartz diorite up to 3 feet in diameter. The formation is a torrential fanglomerate almost devoid of bedding, so much so that it appears at first glance to be granitic basement. Only the finer facies made up of smaller boulders and cobbles show rude bedding in road cuts that reveal the sedimentary origin of the formation. The upper portion of the fanglomerate adjacent to the Edison fault is made up largely of rubble of quartz diorite and hornblende diorite similar to that exposed in place south of the fault. Eastward, in the vicinity of Caliente, the Bealville fanglomerate becomes less coarse and is predominately a cobble conglomerate made up of rounded granitic cobbles and boulders in a loose, sandy or greenish clay matrix.

Age and Correlation. The lower portion of the Bealville fanglomerate was deposited contemporaneously with the Walker formation of lower Miocene-Oligocene age, into which it fingers westward. The upper portion fingers westward into the Bena gravels of lower and middle Miocene age. The formational contact between the Walker and Bena formations is not traceable through the Bealville fanglomerate.

Ilmon Basalt

Definition. The Ilmon basalt flow lies conformably above the Walker formation in lower Caliente Canyon.

Distribution and Thickness. The Ilmon lava ranges from less than an inch in thickness to 100 feet and is traceable through a series of isolated outcrops from a point 2 miles west of Ilmon station northwestward for about 3 miles to the west border of the map. Throughout this area, the lava is overlain by the Bena gravels and sandstone. The most northwesterly outcrop of this lava flow is just beyond the western border of the quadrangle about 3 miles northwest of Bena, where it is about 15 feet thick and separates Walker formation below from Freeman-Jewett shale above.

Lithologic Character. The Ilmon lava flow consists of basalt of a very dark-brown color. It is highly vesicular, containing vesicles averaging

FIGURE 21. Ilmon lava flow a mile northeast of Bena. Bena gravel beds above and Walker beds below. Small fault near left.

about half an inch in diameter, which are evenly distributed and closely spaced. Some are filled or partly filled with secondary calcite. The rock is dense, but generally shows small phenocrysts of feldspar. The rock is massive and without flow structure.

Under the microscope the Ilmon lava is seen to be a basalt with a hyaloophitic texture in which laths of plagioclase are set in a microcrystalline and crystalline groundmass. Intermediate labradorite (An_{60} to An_{64}) forms lath-shaped crystals that show both Carlsbad and albite twins. Although the feldspar is unaltered, the groundmass appears to be made up of dark brownish, cloudy, partially devitrified basic glass in which are set skeletal augite crystals and numerous dustlike particles of magnetite. The unaltered augite is pale brown in color.

Age and Correlation. The Ilmon basalt is probably of lower Miocene (Zemorrian) age, as it lies above the Walker formation (lower Miocene-Oligocene) and the exposure out of the quadrangle 3 miles northwest of Bena lies below the Freeman-Jewett shale of lower Miocene (Saucesian-Zemorrin) age. The Ilmon lava may correlate with the andesite lavas exposed in Cache Canyon northeast of Tehachapi, the nearest occurrence of Tertiary volcanic rocks, or possibly with the basalt and dacite flows in the Tecuya formation at the south end of San Joaquin Valley, all of which are of lithology similar to the Ilmon lava.

Freeman-Jewett Shale

Definition, Distribution and Thickness. The equivalent of the lower Miocene Freeman-Jewett silt of the east side San Joaquin Valley oil fields crops out in Cottonwood Canyon just beyond the western border of the mapped quadrangle, where it is made up of about 500 feet of marine clay shale lying conformably between the Bena gravels above and the Walker formation below. Southeast of this exposure, two outcrops of this shale, separated by a fault, extend a short distance into the quadrangle on the south side of the canyon. Southward the shale pinches out between fluviatile sediments of the Walker and Bena formations.

Lithologic Character. The Freeman-Jewett shale is light grayish-brown, thin-bedded, somewhat punky, semi-siliceous or diatomaceous, and of light weight. It commonly contains thin laminae of fine silty sand.

Age and Correlation. The Freeman-Jewett shale encountered in wells on the east side of San Joaquin Valley carries a lower Miocene (Saucesian-Zemorrian) foraminiferal fauna.

Bena Gravels

Definition. The Bena formation is a series of terrestrial gravels of lower and middle Miocene age lying conformably above the Walker formation and Ilmon basalt and unconformably below the Kern River gravels in lower Caliente Canyon. The Bena formation is the continental facies of the lower and middle Miocene marine formations of eastern San Joaquin Valley.

Distribution and Thickness. The hills 3 miles southeast of Bena are designated as the type locality of the Bena gravels, where they attain a thickness of about 2,500 feet. The formation is also well exposed from Bena northwestward into Cottonwood Canyon, but only the southeastern extremity of this exposure lies within the mapped quadrangle.

FIGURE 22. Walker beds faulted against Bena gravel. Two miles west of Pampa Peak. Bena gravel on top of ridge, Walker beds on slopes, dipping southwest to the left.

Lithologic Character. The Bena formation is a poorly consolidated series of cobble and pebble gravel, arkosic sand, and interbedded gritty clay, all of fluviatile origin. The pebbles and cobbles making up the gravels are well-rounded, some as much as a foot in diameter, but average much less. They are composed mainly of granitic rocks, chiefly quartz diorite and lesser amounts of gneiss, quartzite, schist, quartz, andesite, rhyolite, volcanic porphyries, and translucent chert, set in a matrix of gray to ferruginous rusty-brown sand. The gravels are intimately associated with ill-sorted coarse- to fine-grained, pebbly arkosic sands, usually gray-white but locally iron-stained to rusty buff. Interbedded in places with the gravel and sand are gray gritty clays.

The type section of the Bena formation has no definite sequence, as it is made up of a heterogeneous series of gravel, sand, and clay as described above, with gravel predominating. However, the lower 1,000 feet of the type section contains a bed about 100 feet thick of granite boulder gravel. This layer occurs about 500 feet above the base of the formation. Another occurs as a thick lens about 500 feet stratigraphically higher, but is traceable for only half a mile. Southward along strike, the lower 1,000 feet of Bena formation interfingers with and finally grades into the Bealville granitic fanglomerate as does the underlying Walker formation.

The Bena formation is practically all of continental origin within Breckenridge Mountain quadrangle, but marine fossils found at several localities indicate local marine fingers. The basal sandstone immediately

FIGURE 23. View across Cottonwood Canyon. Note Freeman-Jewett shale in foreground. Two miles west of Pampa Peak.

overlying the Ilmon basalt east of Bena appears to be marine, and has yielded some small pelecypods and some echinoid fragments. The Bena formation is known to grade rapidly down dip and to the west into formations of marine origin. This is attested to by wells drilled south of Bena which encountered marine shale and silt carrying foraminifera and thin-shelled mollusks at shallow depths. A short distance beyond the western border of the quadrangle in Cottonwood Canyon, the Bena gravels overlie the Freeman-Jewett shale and grade laterally into the marine Olcese sandstone and Round Mountain shale to the north.

Age and Correlation. The pelecypod fossils found in the Bena formation are indeterminate, but the age of the Bena formation is determined from that of the marine formations into which it grades westward. The basal portion grades into the Olcese sand, of lower Miocene (Saucesian or "Temblor") age. The remainder grades into the Round Mountain shale, of middle Miocene (Relizian-Luisian) age. The "Santa Margarita" sand of upper Miocene (Mohnian) age is not represented in the mapped area where it is overlapped by the Kern River gravels, but crops out in the low foothills to the west at and near the mouth of Cottonwood Canyon, where it in part overlies and in part grades into the Bena gravels.

Kern River Gravel

Definition. The name "Kern River Beds" was first applied by F. M. Anderson in 1905 (Anderson, 1905, pp. 187-188, 191) to the entire 3,000

FIGURE 24. Terrace cut in Bena and underlying granitic rocks. North side of Caliente Creek between Bena and Ilmon.

foot series of sediments, including the marine Miocene, exposed 2 to 6 miles east of Oil City, Kern County. In a later paper (Anderson, 1911, pp. 95, 111), he redefined as the "Kern River group" the terrigenous gravels, sands, and clays, including the Kern oil measures of Neocene age, unconformably overlying the Miocene "Temblor group". This usage has generally been followed by later authors (Stevens, 1924, p. 33; Fox, 1929, p. 103; and others), who regard the "Kern River series" as the unconsolidated continental gravels, sands and clays of Pliocene-Pleistocene age.

Distribution and Thickness. Within the mapped quadrangle, the Kern River gravel, of Pliocene age, crops out only in the hills immediately south of Bena. This exposure extends another mile and a half to the west out of the quadrangle. The Kern River gravel is extensively exposed in the low foothills beyond the western border of the map west of Cottonwood Canyon, and to the northwest, where it dips very gently west under San Joaquin Valley. A complete section of the Kern River gravels is about 1,200 feet thick in the foothills, with thickness increasing down dip into the valley. However, only the lower 600 feet of the Kern River gravel beds lie within the mapped quadrangle, cropping out in the hills south of Bena and dipping westward.

Lithologic Character. The Kern River gravel is of terrestrial origin and is generally poorly bedded, loosely consolidated and of a prevailing

FIGURE 25. Breckenridge Mountain and Walker Basin.

brown-gray color. The gravel is composed of poorly sorted, rounded to sub-rounded pebbles, cobbles, and some boulders of a great variety of rock types, including volcanic debris ranging from rhyolite to basalt, some porphyritic, some dense, vesicular, or with prominent flow structure, and a considerable amount of quartzite, granitic rocks, gneiss, schist, phyllite, quartz, translucent milky chert, and other less common types. They are set in an ill-sorted gray sandy matrix. In the hills south of Bena, the basal 500 feet of the Kern River gravel is very coarse, being made up of large cobbles and boulders up to 2 feet across. This is overlain by about 600 feet of gray gravelly sand, of which only the basal portion lies within the mapped quadrangle. This is in turn overlain by about 100 feet of coarse cobble gravel which crops out beyond the west border of the map.

The relationship between the Kern River gravel and the underlying Bena gravel in the hills south of Bena is probably a disconformity. Northwest of Bena, outside the mapped area, the relationship is a slight angular unconformity in which the Kern River gravel overlaps the "Santa Margarita" onto the underlying Bena gravel up dip with a discordance of about 10 degrees.

Age and Correlation. The Kern River gravel is the youngest Tertiary formation on the east side of San Joaquin Valley, and is of Pliocene age, possibly extending up into the Pleistocene. It is everywhere of continental origin, although it thickens and becomes fine-grained in the middle of the valley. It correlates with the non-marine Tulare formation of the west side of the valley.

Volcanic Breccia

On the ridge south of Walker Basin 2 miles southeast of Rankin Ranch is an outcrop of gray volcanic breccia, which appears to lie upon the quartz diorite with a westerly dip, but may be a volcanic plug. The rock is made up of angular fragments up to 10 inches long of gray to pink rhyolite or dacite, some showing prominent flow-structure, in a hard tuff matrix. In addition to the dacite rubble, there are fragments of quartz diorite. The rock appears to be pyroclastic and is of somewhat similar lithology to the rhyolite-dacite breccia in the Bealville fanglomerate a mile east-southeast of Caliente, but its isolated occurrence suggests that it is a vent breccia.

Pleistocene Sediments

Terrace Deposits

The largest terrace gravel deposit is on the north side of lower Caliente Canyon. This deposit ranges up to 100 feet in thickness and consists of granitic gravel and sand. Its depositional surface, about 100 feet above the present level of the canyon, is consequently much dissected. Other terrace gravels of smaller extent occur farther up the canyon, and one large one is in Tehachapi Canyon a mile east of Bealville. These terrace gravels are of late Pleistocene age.

Alluvium

Recent alluvium is most extensive in Walker Basin, where it covers an area of about 6 square miles, at an elevation of over 3,300 feet. The thickness here is unknown, but probably exceeds 300 feet, and may be as much as 1,000 feet. The alluvium here consists of granitic pebbly sand admixed with loamy silt.

Alluvium fills the flood plain of Caliente Canyon and those of some of its tributaries, the valley of White Wolf Ranch, and Kern Mesa at the extreme southwest corner of the quadrangle. The alluvium in all these areas is composed of granitic pebbly sand admixed with silty loam, and is as much as 150 feet thick.

STRUCTURE

Structure of the Pre-Cretaceous Complex

The metasediments of the southern Sierra Nevada have been so widely intruded by granitic rocks that little remains of their original structure. However, the residual inclusions of these old sediments indicate an attitude with a general north to northwest strike and near-vertical dip. Except for some local variations discussed below, this attitude is general throughout the mapped quadrangle.

The band of the Kernville series in the southeastern portion of the quadrangle strikes east of north and dips steeply east. Northeast of Walker Basin this band strikes about N. 40° W. and dips very steeply southwest. In Cottonwood Canyon remnants of the Pampa series indicate an S-shaped flexure in vertical beds concave southward at Castro Ranch and convex southwestward where Cottonwood Canyon passes off the map. Dips, though nearly vertical, suggest a south-plunging syncline at Castro Ranch and a southwest-plunging anticlinal nose to the west.

The attitudes of the foliation in the quartz diorite conform to that of the various remnants of Kernville and Pampa series wherever they exist throughout the quadrangle and are thus believed to indicate the preexisting structure of the metasediments. In general, it may be said that the dip of the foliation is vertical and trends nearly north-south in the southern portion of the quadrangle, gradually swinging to northwest throughout the northern portion of the quadrangle. A local east-west trend is developed in the northwestern portion of the quadrangle northward from the Cottonwood Canyon flexure.

Structure of the Tertiary Sediments

The Tertiary sediments exposed in the southwestern foothills in the vicinity of lower Caliente Canyon are tilted about 20° SW., toward San Joaquin Valley. In the hills south of lower Caliente Creek the sediments become folded into a broad, westward-plunging syncline, apparently from drag on the Edison fault which brings up the basement complex on the south. In the hills southeast of Ilmon, the beds dip south at increasingly steep angles up to 60°, directly into the Edison fault. Southeast of Caliente these beds become folded into a rather sharp syncline, a drag fold on the Edison fault as it dies out eastward.

Faults

Kern Canyon Fault. A considerable amount of material has been published on the Kern Canyon fault, traceable for some 40 miles northward from Kernville along Kern Canyon. The geomorphologic features along

FIGURE 26. Walker Basin toward the north. Breckenridge fault follows west edge of valley to left.

FIGURE 27. View north down Havilah Canyon. Kern Canyon fault follows canyon and passes through saddle in distance. Quartz diorite exposures.

this fault have been described in detail by Lawson (1906). Miller and Webb (1940) have mapped the fault through Kernville quadrangle and state that it is a fault line scarp, but arrive at no conclusions regarding its movement. Recently this fault has been mapped through Isabella quadrangle by Treasher (1940, abst.) who states that north of Isabella it is a steep normal fault dipping westward, but southward it reverses its movement and becomes a steep reverse fault dipping in the same direction. Despite all the work done on the Kern Canyon fault, little is known regarding its movement as it lies within rocks of the basement complex and is a strike fault where it cuts through the Kernville series.

South of Kernville the Kern Canyon fault is traceable slightly west of south through Bodfish. It extends for about 3 miles up Havilah Canyon and dies out just south of Havilah Pass. In Havilah Canyon the fault is largely within quartz diorite but is physiographically well expressed, forming a long straight scarp just west of the creek and facing eastward, indicating relative upward movement of the west block.

Breckenridge Fault. About a mile west of the southward-dying Kern Canyon fault, appears another parallel fault which follows the base of the steep east slope of Breckenridge Mountain. This fault is named the Breckenridge fault and is traceable from the northern border of the quadrangle due southward for about 9 miles to Rankin Ranch where it dies out. The fault is a member of the Kern Canyon fault zone and separates the steep eastern front of the Breckenridge Mountain plateau from the flat valley of Walker Basin. The Breckenridge fault has not

FIGURE 28. View east across scarp of Kern River fault. Mouth of Kern River Canyon.

been found exposed, but its existence is clearly indicated by the abrupt rise of the Breckenridge Mountain front along a remarkably straight base. Spurs of this steep mountain front are abruptly terminated along this line by triangular facets facing Walker Basin, and canyons between the spurs are narrow, V-shaped and steep, with small alluvial fans at their mouths. Movement on the fault is mainly if not entirely vertical, with the west block relatively elevated at least as much as the height of Breckenridge Mountain above Walker Basin, or more than 4,000 feet.

The northern portion of the Breckenridge fault appears to divide into two branches, both of which probably die out at or near the northern border of the quadrangle. The Breckenridge fault and its northwestern branch trend generally parallel to the foliation of the quartz diorite in this area.

Dougherty Fault (?). A marked topographic break extending from the northwest corner of the mapped quadrangle southeast for about 5 or 6 miles through and perhaps beyond Hoosier Flat suggests the existence of a fault which will be referred to as the Dougherty fault(?). The topographic evidence of faulting is indicated by an alignment of saddles on ridges; canyons, such as Dougherty, following this line, by the sudden change of course of the Kern River from south to west; and by the sudden break in slope between the high upland mass of Breckenridge Mountain on the northeast and the much lower mountains to the southwest. Further evidence of faulting along this line is indicated in Kern

Figure 29. Cracks along trace of White Wolf fault north of U. S. Highway 466 near Caliente; cracks were developed during Tehachapi earthquake of 1952. *Photo by Lauren A. Wright.*

Canyon where there is a zone of brecciated rock and some gouge, up to about 30 feet wide, but it is not clear cut. On the highway near and parallel to this supposed fault, there is a steep west-dipping plane of movement bounded by vertically grooved quartz diorite. The plane is parallel to the local foliation in the quartz diorite, and may thus be a slippage plane developed along a plane of foliation.

The nature of the movement of the supposed Dougherty fault is not known, but the topography suggests relative elevation of the northeast block. This supposed fault is aligned with the Poso Creek fault northwest of the mapped area, a fault traceable for some 15 miles, but with the upthrown block on the southwest.

Kern River Fault. The Kern River fault (not to be confused with the Kern Canyon fault); is well developed northwest of the mapped area, especially at the mouth of Kern Gorge. It is a normal fault that dips southwest, is traceable for about 15 miles, and forms a very prominent scarp about 2,000 feet high between granitic mountains on the northeast and low sedimentary foothills on the southwest. At Kern Gorge, it dips 55°-60° SW.

The Kern River fault extends about 2 miles east-southeast into Breckenridge Mountain quadrangle where it dips 76° to 80° S. and forms the southern escarpment of Mount Adelaide. The fault is here marked by about 2 feet of gouge with vertical fault grooves. It occurs within the foliated quartz diorite, and trends and dips parallel to the foliation of

FIGURE 30. Cracks in earth between Caliente and Tehachapi Creeks; cracks are result of movement during Tehachapi earthquake of 1952. Widest point in crack is 59 inches; depth about 6 feet. *Photo courtesy Southern Pacific Railroad.*

this rock between Mount Adelaide and Kern Gorge. Like the Dougherty fault (?), the Kern River fault appears to have been developed along a plane of foliation in the quartz diorite.

Cottonwood Canyon Faults. About a mile south of Cottonwood Canyon, a normal fault that dips 60° NE. brings a block of quartz diorite and schist—the schist having a strike parallel to the fault—against southwest-dipping Tertiary sediments that form the northeastern block. A similar fault occurring about a mile farther south, has a more easterly trend parallel to the strike of the schist on the south block.

Within 2 miles beyond the western border of the quadrangle in Cottonwood Canyon, there are many minor faults, mostly normal with the upthrown blocks on the southwest or west, as indicated by their effect on the Tertiary sediments. These faults curve around from northwest to north, and nearly all of them, including those lying within the quadrangle, are strike faults following the trend of the Pampa schist around the Cottonwood Canyon flexure. Such a relationship indicates the faults have originated along foliation planes in the schist which acted as planes of slippage during tectonic movements.

FIGURE 31. Crack in earth above Tunnel 4, Southern Pacific Railroad.
Photo courtesy Southern Pacific Railroad.

Bena Faults. About a mile northwest of Bena are two minor faults, named the Bena faults, trending about N. 70° W. and cutting the Ilmon basalt. The larger of these is traceable for about half a mile and has a vertical displacement of about 25 feet, upthrown on the north. This fault is about vertical.

Ilmon Fault. The Ilmon fault is about 2 miles southwest of Ilmon station and trends N. 45° W. for about a mile in Bena gravels. This fault is of doubtful existence, but is suggested by probable displacement of a boulder conglomerate bed. The upthrown block is probably on the southwest.

Baker Fault. The Baker fault occurs northwest of Caliente and trends about N. 45° W. for at least a mile. It is a normal fault dipping about 65° NE., and brings quartz diorite on the southwest against Walker beds on the northeast which dip into the fault.

Edison Fault. The Edison fault is a major normal fault dipping north, and wells drilled west of the mapped quadrangle indicate this fault to extend, although concealed, for a considerable distance under San Joaquin Valley southeast of Edison where it trends about N. 60° W. and bounds the Edison oil field on the north. This fault extends eastward for about 9 miles into the hills of the southwestern portion of Breckenridge Mountain quadrangle where it is exposed at the surface and trends roughly east. This fault brings the basement complex up on the south against Tertiary sediments on the north with maximum displacement of more than 5,000 feet at the western border of the map, gradually decreasing eastward. The fault is exposed at many places where it is marked by several feet of mylonite, gouge, and pulverized rock, and dips from 28° to 60° N. Its crooked surface trace over the hills is attributed to its low dip at many places, especially in the western 3 miles where it dips only 30°.

The Edison fault was definitely active during deposition of the Bealville fanglomerate as the upper portion of this formation adjacent to the fault is made up of angular rubble of hornblende diorite rocks such as are exposed on the upthrown southern block. However, in marked contrast to the other major faults in the southern Sierra, the Edison fault has no topographic expression. It is obviously an old, dead fault, probably active during Oligocene, Miocene and perhaps Pliocene time, but inactive since that time.

The low dip of this fault may be attributed to a regional southward tilt of the area during Pleistocene time when the fault was inactive. This southward tilt would lessen the dip of this north-dipping fault.

White Wolf Fault. A major fault known as the White Wolf fault trends about N. 50° E. beyond the southern border of the quadrangle and bounds the steep northwestern front of Bear Mountain. Relative upward maximum displacement of the southeastern block amounts to many thousand feet. This fault was traced for about 3 miles northeastward into Breckenridge Mountain quadrangle northeast of White Wolf Ranch, and disappears at Tehachapi Creek. It occurs within biotite-hornblende quartz diorite, but is marked by several feet of gouge and crushed rock. The rock on the northwestern or down-thrown block is highly crushed within a mile of this fault. In marked contrast to the nearby Edison fault, the White Wolf fault is well expressed topographically indicating it to have been active during Quaternary time.*

Structural Blocks

The Breckenridge Mountain quadrangle takes in portions of four tectonic blocks within the southern Sierra Nevada, bounded by major faults. They are:

1. Western block
2. Eastern block
3. White Wolf block
4. Bear Mountain block

Western Block. The major portion of Breckenridge Mountain quadrangle lies within the Western or Greenhorn Mountain block of the Sierra

* The recency of activity of the White Wolf fault is attested to by the violent earthquake of July 21, 1952, which originated on this fault. This developed a discontinuous series of fault fractures at the surface along or near the entire 20-mile known trace of the White Wolf fault, including the northeastern portion lying within the mapped quadrangle. The fractures vary considerably in trend, dip, and movement, but displacements were as great as 3 feet and in general indicated the White Wolf fault to be of the thrust or reverse type in which the southeastern block was displaced upward and northward relative to the northwestern block.

Nevada and is bounded by the Kern Canyon fault on the east. Within Breckenridge Mountain quadrangle, it is a block of basement complex overlain by Tertiary sediments on its southwestern margin and is bounded on the east by the Kern Canyon-Breckenridge fault zone and partially terminated on the south by the Edison fault. The block is elevated, relative to the Eastern block, along the Kern Canyon-Breckenridge fault zone and tilted gently westward toward San Joaquin Valley. In the extreme northwestern part of the quadrangle, this block breaks into several minor blocks separated by the Kern River and Dougherty faults.

Eastern Block. The Breckenridge Mountain quadrangle takes in only a very small portion of the Eastern or Main block of the Sierra Nevada lying between the Kern Canyon and Sierra Nevada faults. This is a block of basement complex bounded on the west by the Kern Canyon-Breckenridge fault zone. Within the mapped quadrangle, the block includes Red Mountain on the west flank of Piute Mountain range which forms the main mass of the southern portion of the Eastern block, Havilah Pass, and the alluviated valley of Walker Basin.

The southern portion of the Eastern block has been tilted westward, having been elevated along Piute Range and depressed relative to the Western block along the Kern Canyon-Breckenridge fault zone. South of Walker Basin, where the Breckenridge fault dies out, the Eastern and Western blocks are united.

White Wolf Block. The southwestern portion of the quadrangle takes in a portion of the White Wolf block, a block of basement rocks between the Edison and White Wolf faults. The block wedges out east of Bealville where the two faults approach each other, but widens westward into San Joaquin Valley as the faults diverge. It is tilted gently westward along with the adjacent Western block toward San Joaquin Valley.

Bear Mountain Block. Only the extreme northern tip of the uplifted Bear Mountain block of basement rocks lies within the mapped-quadrangle. The block is bounded by the White Wolf fault on the nothwest and the Garlock fault some 20 miles to the southeast. The Bear Mountain block is elevated between the two faults and Bear Mountain probably represents the maximum uplift. Northwestward where the White Wolf fault dies out, this block ramps into the Western block.

GEOLOGIC HISTORY

Paleozoic (?): Deposition. The Kernville and Pampa series, the oldest formations in Breckenridge quadrangle, were deposited probably during late Paleozoic and perhaps early Mesozoic time in a widespread, open sea as alternating sand, silt, clay, and limestone beds. These sediments accumulated to a tremendous thickness on a sea floor which must have subsided continuously during deposition resulting in a very deep burial of the lower sediments.

Jurassic: Orogeny. After the Kernville and Pampa sediments were deposited the entire Sierra Nevada region was affected by a great orogeny known as the Nevadan orogeny at the close of Jurassic time. This diastrophism resulted in the entire region emerging from sea and caused the thick sedimentary series to be tightly compressed into sharp, perhaps isoclinal folds trending generally north-south, indicating an intense east-west compressive force. The great depth at which the sediments became infolded resulted in dynamic and thermal metamorphism causing them to become recrystallized into quartzite, schist, and marble.

The metamorphism of the Kernville and Pampa series was accompanied or followed by widespread invasion of granitic magmas. These appear to have been intruded in several waves in which quartz diorite was gradually emplaced first into the Kernville and Pampa series bed by bed, causing foliation to develop. Two small stocks of gabbro-diorite were intruded with the quartz diorite in the western part of the quadrangle. The invasion of these granitic magmas culminated in several large intrusions of quartz diorite in irregular masses. The granitic invasions became so widespread as to form the Sierra Nevada batholith leaving only small pendants of the original Kernville and Pampa series. The Nevadan orogeny no doubt resulted in the building up of high mountains in the mapped area as well as throughout the Sierra Nevada region. The development of pegmatites along fissures of the crystallized granitic rocks represents the final stage of the granitic invasion.

Cretaceous-Eocene: Erosion. The Cretaceous-Eocene record is lacking within Breckenridge Mountain quadrangle. This was a time during which the mountains that rose during the Nevadan orogeny supposedly were eroded. There were probably several recurrent periods of uplift and erosion during this long interval, but the region was reduced to low relief at the end of Eocene time.

Oligocene: Diastrophism and Deposition. During Oligocene time much of the southern Sierra Nevada region, including the eastern portion of Breckenridge Mountain quadrangle, was re-elevated into rugged mountains. Some of the local faults, such as the Edison fault, probably originated and became active during this disturbance.

The mountains developed during the Oligocene orogeny underwent erosion by torrential storms, and the eroded rubble was dumped in a valley emerging from these mountains, at the present site of Caliente Canyon, to form the Bealville fanglomerate which accumulated to a great thickness during Oligocene time. Immediately beyond this alluvial fan, finer material was carried by out-flowing streams into the margin of San Joaquin Valley and deposited as alluvial gravels and sands of the Walker formation. Some volcanic explosive activity in a nearby area resulted in an admixture of pumice fragments and tuffaceous material in the Walker sediments.

Miocene: Deposition. During Miocene time, the northeastern portion of Breckenridge Mountain quadrangle continued to undergo erosion, and deposition of the torrential Bealville fanglomerates continued uninterrupted at the present site of Caliente Canyon.

Deposition of the Walker beds was followed by local volcanism resulting in the extrusion of the Ilmon basalt at the site of lower Caliente Canyon. This was in turn followed by accumulation of the Bena alluvial gravels and sands on the site of the present foothills which was the margin of the San Joaquin Valley during Miocene time. The local volcanism was also followed by submergence of the San Joaquin Valley alluvial plain under a shallow sea which persisted through the Miocene, and which barely extended from the west into Breckenridge Mountain quadrangle as indicated by the occurrence of the Freeman-Jewett marine shale under the Bena gravels and by some local marine sands in the Bena gravels. The Edison fault continued active through Miocene time and formed a north-facing scarp between the elevated White Wolf block on the south, in which plutonic rocks were exposed and undergoing erosion during at least part of Miocene time, and the depressed block on the north in which sediments were deposited.

It is not known how much of the area of the mapped quadrangle underwent deposition during Oliogocene and Miocene time, but it is probable that Tertiary fluvatile sediments covered most if not all of the southwestern half.

Pliocene: Diastrophism and Deposition. In early Pliocene time, following deposition of the Bena gravels, the region probably was slightly uplifted, which resulted in erosion of the granitic rocks and the previously deposited Tertiary sediments. The material eroded was carried westward and deposited during Pliocene time as terrigenous gravels of the Kern River formation on the eastern San Joaquin Valley which emerged from the sea in late Miocene or early Pliocene time to become a broad alluvial plain.

Pleistocene: Cascadian Orogeny. Early Pleistocene time was a period of uplift and erosion of the Sierra Nevada region, and constitutes a major phase of the Cascadian orogeny. During this disturbance the entire area lying within the quadrangle was tilted westward, was eroded, and the present stream pattern developed. This great regional uplift involved the Tertiary sediments deposited at the margin of San Joaquin Valley and the area of granitic rocks now exposed south of the Edison fault causing erosion of both to form the present foothills. The Edison fault, active during Tertiary diastrophism and deposition, apparently was inactive during the Pleistocene orogeny. However, most of the other major faults and resultant fault blocks probably originated during this disturbance.

Middle Pleistocene time was apparently a time of relative quiescence when the Breckenridge Mountain quadrangle as well as much of the Sierra Nevada region underwent erosion to late maturity or old age stage of the first cycle of erosion.

Late Pleistocene time was the final and culminating stage of the Cascadian orogeny when the Sierra Nevada region was uplifted to its present height. Within the mapped quadrangle, the major faults other than the Edison fault were active during this disturbance resulting in differential elevation of the fault blocks to their present heights. This re-elevated region is being eroded mainly by deepening of the stream channels, and is now in the late youth or early maturity stage of a second cycle of erosion.

MINERAL RESOURCES

Oil and Gas

A total of ten wells has been drilled for oil or gas in Breckenridge Mountain quadrangle, all in the vicinity of Bena. Most of these were drilled prior to 1917, so that records are poor or lacking.

In sec. 23, T. 30 S., R. 30 E., four wells drilled in a canyon 2 miles south of Bena to depths ranging from 600 feet to 2,000 feet, prior to 1917.

FIGURE 32. Tungsten Chief mill.

Two of these were reported to have produced a small amount of heavy oil along with water. In 1944, Gene Reid Company drilled No. "Tejon" 3 near one of these old producers to 2,700 feet and abandoned it without obtaining production. Four shallow dry holes were drilled southwest of these in secs. 22 and 27, T. 30 S., R 30 E., and abandoned. In 1945, Gene Reid Company drilled its No. "Tejon" 4 in sec. 14, T. 30 S., R. 30 E., to 2,700 feet and abandoned it without showings. In 1929, a dry hole was drilled at Bena by Elmer Oil Company to a reported depth of 5,057 feet.

All of the above wells were spudded in westward-dipping Bena gravel, and the deeper ones probably bottomed in the Walker beds. Several, if not all, of the wells encountered shallow marine sands and shales of probable middle Miocene age at shallow depths.

It is hardly likely that any oil or gas in commercial quantities will ever be produced from Breckenridge Mountain quadrangle as the Tertiary formations are limited to lower Caliente Canyon, and all are exposed without structural closure. Stratigraphic conditions are not favorable as the formations are made up largely of coarse terrestrial gravels and sands.

Tungsten

Mining activity within Breckenridge Mountain quadrangle is confined almost entirely to the area of metamorphic rocks north of Walker Basin where small quantities of tungsten ore in the form of scheelite are mined. The scheelite occurs in metamorphic zones in crystalline limestone in contact with dikes of quartz diorite. These contact zones are made up largely of crystalline masses of red-brown garnet, and contain considerable admixtures of calcite, quartz, gray epidote, diopside, clinozoisite and small quantities of scheelite. The ore is of low grade. The zones are as much as 25 feet thick and are vertical, striking west of north.

A total of 15 workings has been developed and mining is done chiefly along horizontal tunnels and inclines. All are in the prospect stage and are idle at present. Most of these workings are on a group of claims owned by the Tungsten Chief Mining Company. There is no mill at present.

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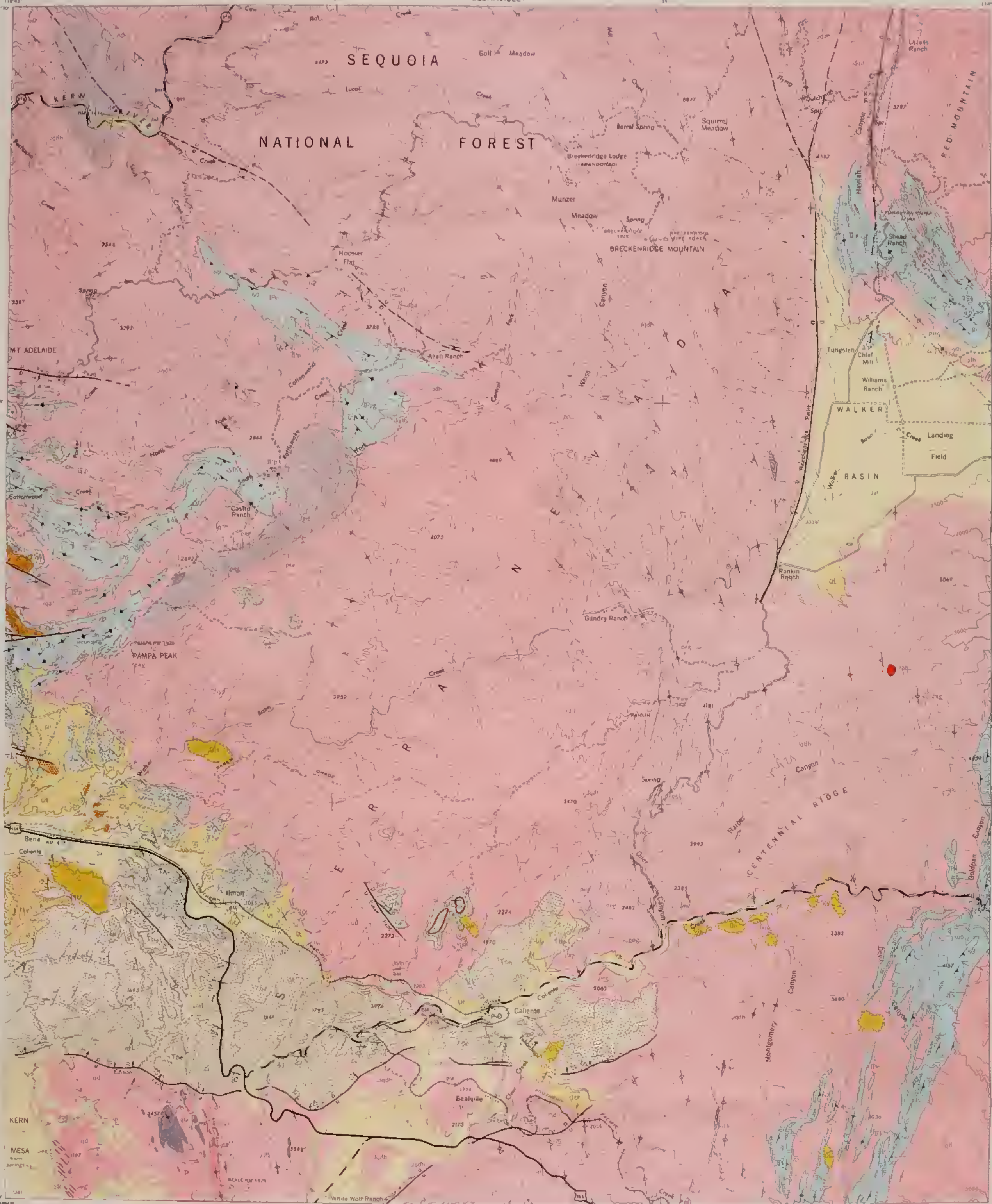

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GEOLOGIC MAP OF THE BRECKENRIDGE MOUNTAIN QUADRANGLE, CALIFORNIA

By T. W. Dibblee, Jr.

Scale 1:62,500

CONTOUR INTERVAL 100 FEET
DATUM IS MEAN SEA LEVEL

Geology by T. W. Dibblee, Jr.
Surveyed in 1950

LEGEND

SEDIMENTARY AND VOLCANIC ROCKS

CENOZOIC — QUATERNARY — Recent
- Landslide
- Qal — Alluvium (sand, gravel and silt)

Pleistocene
- Qt — Terraces (stream-laid sand and gravel)

UNCONFORMITY

TERTIARY — Plio-Pleistocene
- Tkr — Kern River gravel (cobble and pebble gravel, sand and silt)

DISCONFORMITY

Miocene
- Tbs — Bena gravel (pebbly granitic sand and gravel)
- Freeman-Jewett shale (thin-bedded silty to sandy shale)
- Ilmon andesite
- Tba — Bealville fanglomerate (unsorted granitic boulder debris)

Oligocene
- Tw — Walker formation (granitic sandstone, conglomerate, siltstone and tuff breccia)

INTRUSIVE ROCKS

- Andesite breccia

MESOZOIC — Jurassic
- Jqd — Biotite-quartz diorite
- Jqdh — Biotite-hornblende-quartz diorite
- Jgn — Biotite-hornblende-quartz diorite gneiss
- Jgd — Gabbro and gabbro-diorite including olivine norite
- Jh — Hornblendite and other ultra-basic rocks
- peg — Pegmatite dikes
- Qtz — Quartz veins

METAMORPHIC ROCKS

PALEOZOIC
- Pp — Pampa schist (mica schist, with chiastolite (c), and chlorite-greenstone (g))
- Pk — Kernville schist (mica schist, with minor quartzite (q), limestone (ls), and lucite (l))

SYMBOLS

- Alluvium and terrace boundaries
- Contact (dashed where approximately located)
- Fault, showing dip (dashed where approximately located)
- Fault (U, upthrown side, D, downthrown side)
- Strike and dip of beds
- Strike and dip of foliation in schists, mostly concordant with bedding
- Strike of vertical foliation in schists
- Strike and dip of foliation in granitic rocks
- Strike of vertical foliation in granitic rocks

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BULLETIN 168 PLATE 2

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ECONOMIC MAP OF THE BRECKENRIDGE MOUNTAIN QUADRANGLE, CALIFORNIA

By T. W. Dibblee, Jr.

Scale 1:62,500

CONTOUR INTERVAL 100 FEET
DATUM IS MEAN SEA LEVEL

Geology by T. W. Dibblee, Jr.
Surveyed in 1950

Land grid from Caliente quadrangle 1:125,000

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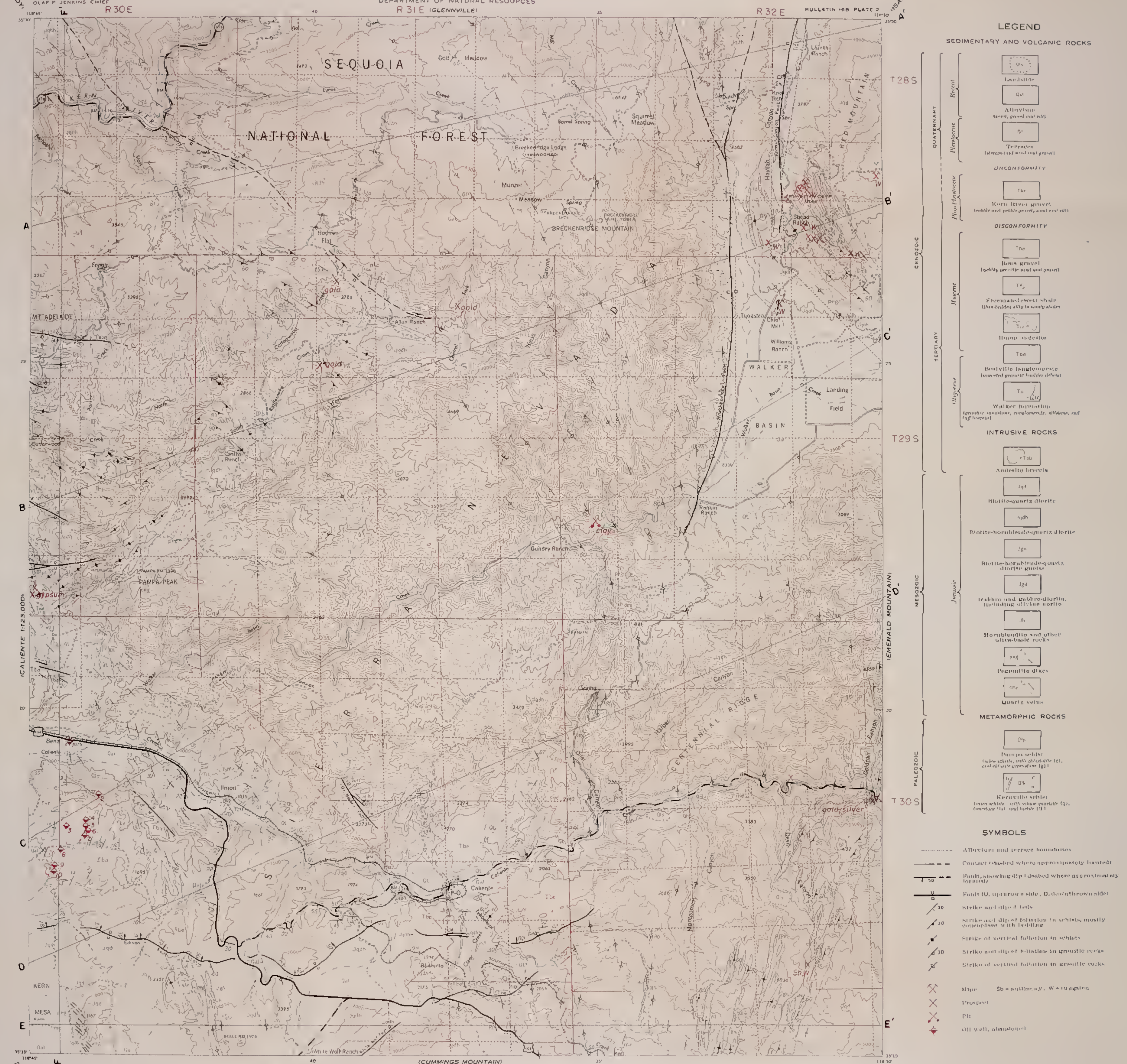

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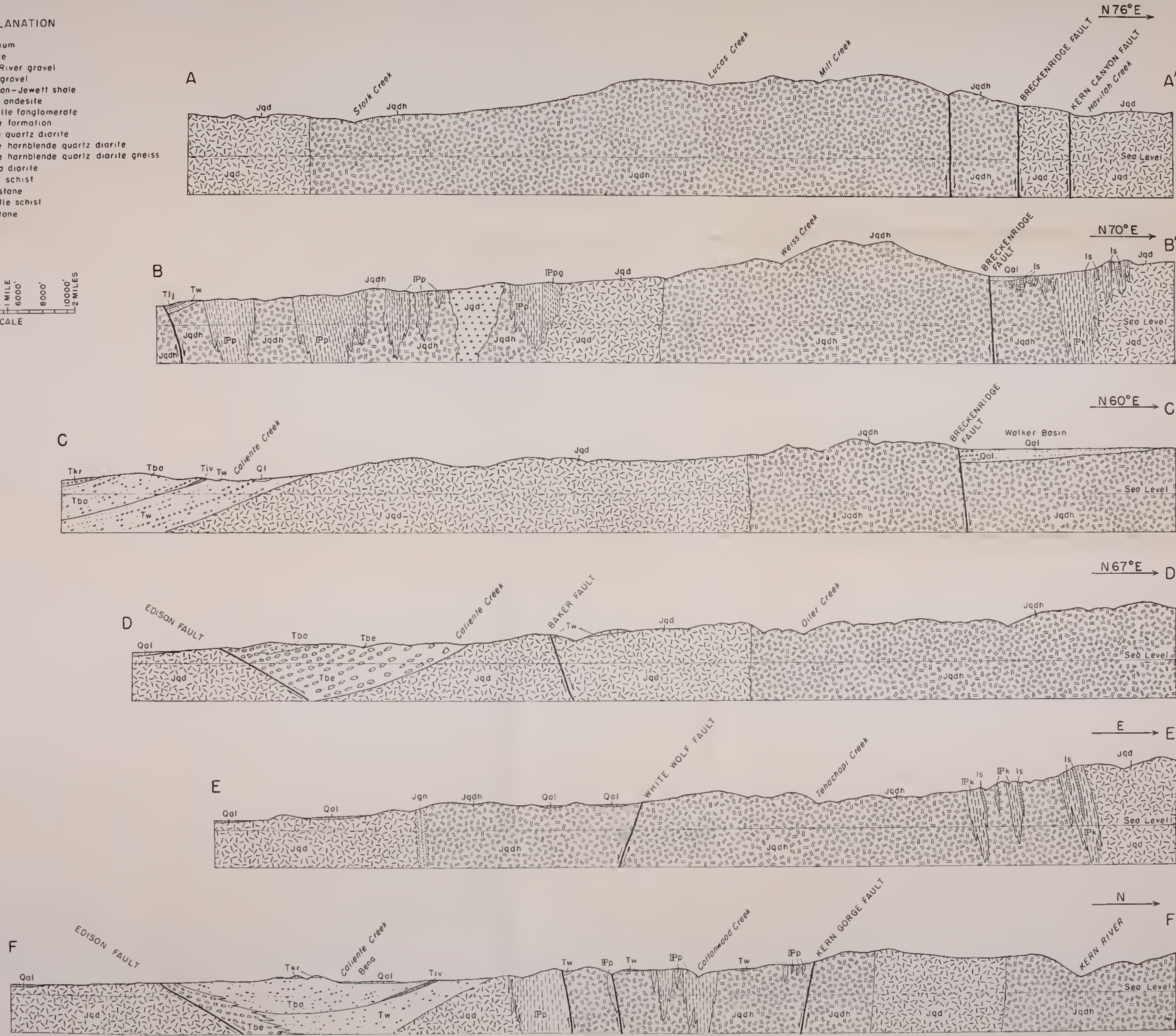
EXPLANATION

- Qal – Alluvium
- Qt – Terrace
- Tkr – Kern River gravel
- Tbo – Bena gravel
- Tfj – Freeman-Jewett shale
- Tiv – Ilmon andesite
- Tbe – Bealville fanglomerate
- Tw – Walker formation
- Jqd – Biotite quartz diorite
- Jqdh – Biotite hornblende quartz diorite
- Jgn – Biotite hornblende quartz diorite gneiss
- Jgd – Gabbro diorite
- ℙp – Pampa schist
- ℙpg – Greenstone
- ℙk – Kernville schist
- ls – Limestone

0 2000' 4000' 1 MILE 6000' 8000' 10000' 2 MILES
SCALE



GEOLOGIC SECTIONS THROUGH BRECKENRIDGE MOUNTAIN QUADRANGLE, CALIFORNIA

By T W Dibblee Jr. 1950